REPORT

ON

THE RIVER HÚGLI

BY

L. F. VERNON-HARCOURT.

DECEMBER 1896.

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To

The COMMISSIONERS for the PORT of CALCUTTA.

Gentlemen,

According to your instructions, conveyed to me through Mr. Duff Bruce on the 31st of December, 1895, I started for India on the 3rd of January last, for the purpose of inspecting the River Húgli, with the object of reporting to you on its improvement for navigation.

Soon after my arrival in Calcutta, your Vice-Chairman, Mr. J. H. Apjohn, in a letter, dated the 28th of January 1896, defined my duties with greater precision, by quoting for my information your resolution of the 21st of December, 1895, as follows :—

"Resolved that in view of the state of public feeling regarding the condition "of the Húgli, it is advisable that the question of the feasibility of improving the "river should be settled once for all, and that Mr. Vernon-Harcourt's terms be "accepted, subject to the approval of Government."

In compliance with the above resolution, he instructed me, in the same communication, to consider all methods by which the Húgli might possibly be improved for navigation purposes, whether by dredging, training, or any other measures which I could advise should be adopted. He, moreover, added further, that he would esteem it a favour if I would give an opinion, from such data as might come under my consideration, as to whether the Húgli is deteriorating from its former condition.

On the morning of the day I reached Calcutta, Mr. Apjohn introduced me to your Deputy Conservator, Captain E. W. Petley, R.N., who brought out for my inspection numerous charts of the river taken at various dates, records of tidal observations, and other documents in his office ; and Captain Petley further gave me a considerable amount of information with respect to the surveys of the river, the changes in the channels and bars, and the river notices issued to pilots. In company with Captain Petley, I made a thorough inspection of the Húgli between Calcutta and the sea ; I also went up the Rupnarain at low tide as far as Tumlook, accompanied by Mr. H. D. Waller, Captain of the "Tigris," survey vessel ; and Mr. Apjohn showed me the portion of the Húgli above Calcutta up to Barrackpur. Mr. D. B. Horn, Superintending Engineer of the South Western Circle, and Mr. M. J. Norman, Executive Engineer of the Nadia Rivers Division,

accompanied me in a visit to the inlet of the Bhagirathi from the Ganges at Naranpur, when we also saw the neighbouring, partially silted-up Chowrasia channel, which was the inlet channel from the Ganges from 1871 to 1881 ; and I further inspected a portion of the Bhagirathi in the neighbourhood of its inlet, and crossed it at Jangipur.

Some cross sections of the Húgli, between Calcutta and Diamond Harbour, and a longitudinal section along the navigable channel from Calcutta to the sea, were taken, at my request, in February last, by the river surveyors, under the instructions of Captain Petley, with the object of enabling me to compare the existing state of the river with its condition at previous periods. Captain Petley also supplied me with copies of several charts of the river, and some tidal diagrams ; and by the courtesy of the Hydrographer, I procured from the Admiralty copies of Lloyd's charts of the river Húgli of 1836, and the sea-face of the Ganges delta of 1837-40. The drawings accompanying the Report have been made by aid of selections from these documents, which have also proved very valuable for the preparation of the Report. The former reports also on the Húgli and its tributaries, to which I have been able to gain access, have been consulted ; and references are made to them in the course of the Report.

I desire to tender my best thanks to Mr. Apjohn for so kindly furthering my investigations during my stay in India, and to express my great obligations to Captain Petley for the assistance he gave me in investigating the records in his office, and in the inspection of the Húgli, and for the further information he has so readily supplied me with in reply to my inquiries since my return to England. I am also much indebted to Mr. Horn for arranging our visit to the inlet of the Bhagirathi from the Ganges, for furnishing me with the records of the flood levels, for several years back, at Rampur-Bauleah, Berhampur, and Noaserai, and for giving me particulars about the overflow of the Damuda.

The consciousness of the vital importance of the questions submitted for my consideration, in regard to the future of the Port of Calcutta, as evidenced by the terms of your resolution, has necessarily led me, in drawing up the accompanying Report, to devote the most careful attention to the indications afforded by my inspection of the Húgli, a comparison of the various charts, and a consideration of all other available information, as to the existing condition of the river, the changes which have occurred in the channels, and the practicability of improving the river for navigation.

In the Report, the changes in the inlets of the Nadia rivers, and the variations in their flood-levels, are first dealt with ; and the fresh-water discharges of the feeders and tributaries of the Húgli, the amount and nature of the alluvium brought down by the Húgli, and the tidal condition of the river are then considered in succession. The changes in the river and estuary are next investigated, by a comparison of the charts of different periods, to enable an opinion to be formed as to the question whether the Húgli is deteriorating from its former condition. Lastly, the feasibility of improving the Húgli is discussed, and proposals are made for ameliorating the navigable condition of the river.

The Report is illustrated by twelve drawings, indicating the general physical conditions and present state of the Húgli, furnishing a ready comparison between its previous and present condition, and showing the training works proposed for its improvement. The first drawing contains a map of the Húgli with its feeders and tributaries, from the Ganges to the Sandheads; a plan showing the different positions of the inlets of the Bhagirathi from the Ganges since 1822; a general plan of the river Húgli from Calcutta to the sea, compiled from recent charts; and diagrams of the tidal flow in the Húgli, both in the dry season and during the freshets. The second drawing shows side by side, for comparison, charts of the Húgli from Barrackpur to Cossipur, of 1873 and 1886, and from Calcutta to Luff Point, of 1836 and 1888; and a chart from the head of Sankral Sand to Buj-Buj Sand of 1780-81; and it exhibits longitudinal sections along the navigable channel of the river, taken from the charts of 1873 and 1886, from Barrackpur to Cossipur. The third drawing comprises cross sections of the Húgli, of different dates, at twelve points between Calcutta and Buffalo Point; and longitudinal sections of the river along the navigable channel from Calcutta to the sea, at various dates between 1813-14 and 1896. The fourth and fifth drawings contain charts and longitudinal and cross sections of the Húgli between Calcutta and Húgli Point, obtained from the large-scale surveys of 1882-3 and 1896, so that the conditions of the river at these dates may be readily compared. The sixth drawing exhibits charts and cross sections of the Moyapur reach, longitudinal sections along the navigable channel of different dates, and longitudinal and cross sections of the proposed training wall indicated on the chart of January 1896. The seventh and eighth drawings contain charts and longitudinal and cross sections of the James and Mary reach of various dates; and also longitudinal and cross sections of the proposed training wall indicated on the chart of December 1895. The ninth and tenth drawings furnish charts of the estuary of the Húgli, from Luff Point to the sea in 1888 and 1894-5, with outlines in red of the charts of 1836 and 1883-4 on each of these charts, respectively; and the courses of the navigable channel through the estuary, as obtained from the several surveys, are shown by lines on an outline map of the estuary on the ninth drawing. The eleventh drawing contains a chart of the estuary of 1895-6, with longitudinal sections; and the twelfth drawing gives charts of the Sandheads of 1768-70, 1837-40, and 1896, and a chart of the sea-face of the Ganges delta, with the fathom lines of the charts of 1837-40 and 1877-87 shown on it in red and black, respectively.

I remain, Gentlemen,

Your Obedient Servant,

L. F. VERNON-HARCOURT.

REPORT ON THE RIVER HÚGLI.

CONTENTS.

I.—General Physical Conditions of the River Húgli.

THE NADIA RIVERS.

FRESH-WATER DISCHARGE OF THE RIVER HÚGLI AND ITS TRIBUTARIES.

ALLUVIUM BROUGHT DOWN BY THE RIVER HÚGLI.

TIDES OF THE RIVER HÚGLI.

TIDAL FLOW INTO THE RIVER HÚGLI.

INFLUENCES OF THE TIDE ON THE RIVER HÚGLI.

II.—Changes in the River Húgli.

COMPARISON OF CHARTS OF THE RIVER HÚGLI.

CHANGES IN THE RIVER HÚGLI BETWEEN CALCUTTA AND HÚGLI POINT.

CHANGES IN THE RIVER HÚGLI BETWEEN HÚGLI POINT AND KANTABARIA.

CONCLUSIONS AS TO CHANGES IN THE RIVER HÚGLI ABOVE ITS ESTUARY.

CHANGES IN THE HÚGLI ESTUARY.

CHANGES IN THE SEA-FACE OF THE GANGES DELTA.

III.—Improvement of the River Húgli.

IMPROVEMENT OF THE JAMES AND MARY REACH.

MOYAPUR TRAINING WALL.

DREDGING IN THE HÚGLI ESTUARY ... 94

RIVER HÚGLI.

CONTENTS OF PLATES.

Plan No. 4.

RIVER HÚGLI.

Surveys of 1882-83 and 1896.

Fig. 1. Ghusri Sand to Achipur, 1882-3.
Fig. 2. Ghusri Sand to Achipur, 1896.
Fig. 3. Achipur Point to Luff Point, 1882-3.
Fig. 4. Achipur Point to Luff Point, 1896.

Plan No. 5.

RIVER HÚGLI.

Sections, 1882-83 and 1896.

Figs. 1 to 26. Cross Sections, Shalimar Sand to Fulta Point, 1882-3, and 1896.
Fig. 27. Longitudinal Sections, Howrah Bridge to Húgli Point, 1882-3 and 1896.

Plan No. 6.

RIVER HÚGLI.

MOYAPUR REACH.

Surveys, Sections, and Training Works.

Fig. 1. Surveys, July, 1873 and 1883.
Fig. 2. Surveys, June, 1886 and July, 1894.
Fig. 3. Survey, January, 1896, with Line of proposed Training Wall.
Fig. 4. Cross Sections near Achipur Point, 1883, July, 1894, and January, 1896.
Fig. 5. Cross Sections near Moyapur Magazine, 1883, July, 1894, and January, 1896.
Fig. 6. Longitudinal Sections, 1883, July, 1894, and January, 1896.
Fig. 7. Longitudinal Section along proposed Training Wall.
Fig. 8. Average Section of Training Wall.

Plan No. 7.

RIVER HÚGLI.

JAMES AND MARY REACH.

Surveys, 1826 to 1895.

Fig. 1. Surveys, November 1826, April 1857, and April and May, 1875.
Fig. 2. Surveys, 1882-83, and April, 1890.
Fig. 3. Surveys, June, 1894, and January, 1895.
Fig. 4. Survey, December, 1895, with Line of proposed Training Wall.

Plan No. 8.

RIVER HÚGLI.

JAMES AND MARY REACH.

Sections and Training Works.

Fig. 1. Cross Sections at Fulta Point, 1882-83, April, 1890, and January, 1895.
Fig. 2. Cross Sections at Lower Ninan, 1882-83, April, 1890, and January, 1895.

REPORT

ON

THE RIVER HÚGLI,

WITH REFERENCE TO ITS GENERAL PHYSICAL CONDITIONS, THE CHANGES IT HAS UNDERGONE, AND THE FEASIBILITY OF IMPROVING IT FOR NAVIGATION.

BY

LEVESON FRANCIS VERNON-HARCOURT, M.A., M.INST.C.E.

To

The COMMISSIONERS for the PORT of CALCUTTA.

I.—General Physical Conditions of the River Húgli.

THE NADIA RIVERS.

Sources of the River Húgli.—The Húgli is formed by the confluence of the Bhagirathi, the Jellinghi, and the Matabanga, the first deltaic offshoots from the Ganges, known as the Nadia rivers, Plate I, Fig. 1. The Bhagirathi is the first and principal offshoot of the three, its supply from the Ganges being quite equal to the combined discharges of the other two. The Bhagirathi also receives, on its right bank, the discharge of four tributaries, the Bansloe, the Dwarka, the Kana, and the Adjai, with some minor streams, draining altogether an area of about 8,700 square miles of country to the west of the Bhagirathi. The Húgli commences at the confluence of the Bhagirathi and the Jellinghi opposite Nadia, about 79 miles above Calcutta; whilst the Matabanga joins the Húgli about 30 miles lower down.

Changes in the Inlets of the Nadia Rivers.—The positions of the inlets of the Nadia rivers, and their sizes and depths, vary with the alterations in the channel of the Ganges in that locality, which frequently changes its course during the flood season. The inlet of the Bhagirathi has shifted since 1822, between Farraka, the upper north-western limit, which was the site of the inlet in 1887-88, and Chowrasia, the lower south-eastern limit, where the inlet channel remained from 1871 to 1881, the distance apart of these extreme positions being about 23 miles, Plate 1, Fig. 2. Similar changes, within smaller limits, have occurred in the positions of the inlets of the Jellinghi and Matabanga, which are near one another, about fifty to sixty miles lower down the Ganges than the Bhagirathi inlet.* In spite, however, of the very changeable course

* Report on the Nuddea Rivers, by Captain John Lang, Calcutta, 1851, Plates 1 and 2.

of the Ganges, inlets have always been formed in flood-time into the three Nadia rivers, by the waters of the Ganges finding vents through depressions in its right bank, the remains probably of some previous inlet channels.

Flood-Levels of the Nadia Rivers in relation to the Ganges.—The changes in the inlets of the Nadia rivers, in conjunction with the variable duration of the flood of the Ganges, though producing considerable variations in the navigable condition of the entrance channels into these rivers from year to year during the dry season, do not appear to affect materially the flood discharge of these rivers, for the cross section of the Bhagirathi at Berhampur seems not to have undergone much alteration during the last twenty years. Moreover, the average flood-levels at Berhampur during the last ten years, from July to October, were higher than in the two previous decades, 1866-75 and 1876-85, by 1 foot and $2\frac{2}{3}$ feet, respectively. The readings, indeed, of the heights of the floods on the gauges in the Ganges at Rampur-Bauleah and in the Bhagirathi at Berhampur, during the four flood months from July to October, show that the Bhagirathi approached nearer to the height of the Ganges from 1885 to 1895 than from 1876 to 1884. These periods did not coincide with particular positions of the inlet; but the Ganges has maintained a more westerly position, closer to the Bhagirathi, during recent years. The relatively higher level of the Bhagirathi in regard to the Ganges during the flood seasons of the later period, might be caused by a freer influx of the flood waters of the Ganges into the Bhagirathi, or by a restriction of the cross section of this river from the accumulation of silt. As, however, no material reduction in the cross section of the Bhagirathi at Berhampur is believed to have taken place within recent years, it is probable that the Ganges, which has itself maintained a higher flood-level, by $9\frac{1}{2}$ inches on the average, between 1885 and 1895 than between 1876 and 1884, in spite of the smaller rise and shorter duration of the flood of 1895, has discharged more freely into the Bhagirathi during the last eleven years, raising the average flood-level in this period nearly 3 feet higher at Berhampur than during the preceding nine years.

A similar increase in the height of the average flood-level, of a little over one foot, during the last ten years as compared with the preceding decade, has been observed in the Húgli at Noaserai, about 14 miles below the confluence of the Matabanga. Moreover, sections across the Húgli at Dumardaha, two miles above Noaserai, taken by Captain Petley in 1889, and this year, indicate a slight increase in sectional area since 1889. Accordingly it appears probable that the flood discharges of the Jellinghi and the Matabanga have also been greater, on the average, within recent years.

FRESH-WATER DISCHARGES OF THE RIVER HÚGLI AND ITS TRIBUTARIES.

Fresh-Water Feeders of the River Húgli.—The fresh-water supply of the Húgli above Calcutta is derived from the flood overflow from the Ganges into the Nadia rivers, and the discharge of the tributaries of the Bhagirathi flowing in on the right bank. The Húgli receives no further important accession of fresh water between the confluence of the Matabanga, nearly fifty miles above

Calcutta, and the mouth of the Damuda on the right bank, 37 miles below Calcutta. Only 5 miles lower down, the Rupnarain flows in on the right bank, like all the ordinary tributaries of the Bhagirathi and the Húgli, as the delta of the Ganges stretches out from the left bank, being bounded on the west by the Bhagirathi and the Húgli. The remaining tributaries, the Haldia and Rasulpur, enter the wide estuary of the Húgli at Haldia Point and Hijili, about 68 and 87 miles respectively below Calcutta, Plate 1, Fig. 3.

Supply of the Nadia Rivers from the Ganges.—The three Nadia rivers receive a supply of water from the Ganges, which has been estimated as ranging from 200,000 cubic feet per second during the height of the freshets, down to almost nothing at the lowest stage of the Ganges ; and the average yearly influx from the Ganges into the Nadia rivers was estimated by Mr. J. A. Longridge at over 60,000 million cubic yards.* About nine-tenths of this influx takes place between June and October ; and the flow falls to a minimum in March and April, when the Ganges is at its lowest level towards the close of the dry season.

Discharge of the Tributaries of the River Bhagirathi.—The discharge of the rivers draining the district lying to the west of the Bhagirathi, is much more irregular during the rainy season than the influx from the Ganges, attaining a maximun discharge of 300,000 to 450,000 cubic feet per second at the height of the floods, which come down about once a month during the rains and last three or four days, and falling to an average of about 70,000 cubic feet per second during the rest of the rainy season, according to the statement in Mr. H. Leonard's report.† The limited area of the basins of these rivers, as compared with the very extensive basin of the Ganges, makes their discharge depend entirely upon the local yearly rainfall which, with an average of 52 inches, has varied, since 1883, between 38 inches in 1884 and 1895, and 65 and 64 inches in 1886 and 1890, respectively. ‡ For the same reason, the driest years over the drainage area of the tributaries of the Bhagirathi do not always coincide with the smallest rise of the Ganges ; for the Ganges had a lower flood-level in 1883, when the rainfall over the Bhagirathi basin averaged 45 inches, than in 1884 with a minimum rainfall over this area of 38 inches, and a flood-level of the Ganges in 1888, averaging nearly a foot less than in 1884, coincided with a rainfall of 55 inches over the Bhagirathi basin. Moreover, though a large rainfall over the Bhagirathi basin generally corresponds with a high rise of the Ganges, the Ganges had a higher rise, averaging about $1\frac{1}{3}$ feet more, in 1894, when the rainfall over the Bhagirathi basin averaged 57 inches, than in 1893, when the corresponding rainfall was 63 inches.

Calculating the average yearly discharge of the tributaries of the Bhagirathi from the above data, it may be estimated to amount to about 40,000 million

* The Hooghly and the Mutla, by J. A. Longridge, Proceedings of the Inst. C. E., vol. XXI., p. 15.

† Report on the River Hooghly, by Hugh Leonard, 1865, p. 5.

‡ The amounts of yearly rainfall have been deduced from the excellent coloured maps, indicating the results of the annual records of rainfall in Bengal, drawn up by the Meteorological Department at Calcutta kindly shown me by Mr. A. Pedler.

cubic yards ; but it must vary considerably from year to year according to the rainfall.

Fresh-water Flow of the River Húgli past Calcutta.—When a high flood of all the Bhagirathi tributaries coincides with the maximum influx from the Ganges into the Nadia rivers, the flow of the Húgli past Calcutta might reach a maximum of about 650,000 cubic feet per second for a short period.

Some water flows down the tributaries of the Húgli during the dry season, even when the streams are dried up and the inlets from the Ganges closed, owing to the percolation of water from the land through the bed and banks of the rivers, which, according to a rough gauging referred to by Mr. Leonard, amounts to 20,000 cubic feet per second thirty miles above Calcutta.* The discharge from this cause past Calcutta, from November to June, has been estimated at from 20,000 to 50,000 cubic feet per second of clear water. †

Adding the above dry-weather flow to the estimated influx from the Ganges into the Nadia rivers, and the discharge of the tributaries of the Bhagirathi, the average yearly fresh-water flow of the Húgli past Calcutta may be reckoned at about 126,000 million cubic yards.

Fresh-water Discharge of the Rivers Damuda and Rupnarain.—A considerable area of land, lying between the west bank of the Húgli and the hills, is drained by the Damuda and the Rupnarain, which together discharge nearly 700,000 cubic feet per second during high floods. These floods come down about once a month during the rainy season, and last two or three days; whilst for the remainder of the rains, the discharge has been estimated to amount to about one-fourth of the flood discharge. ‡ During the dry season, the discharge of these rivers is very small.

The Damuda, which drains a much larger basin than the Rupnarain, has a flood discharge of 474,000 cubic feet per second near Sangatgola, about 12 miles above Burdwan; and the flood discharge of the Rupnarain has been estimated at 224,000 cubic feet per second. § The channel, however, of the Damuda becomes so restricted lower down that, owing to large breaches in its embankments, caused by floods, especially the Begooa breach formed in 1851, and the removal of thirty-five miles of the embankment along the right bank in 1856, about 439,000 cubic feet per second of the flood discharge leave the river, and flooding the land between the Damuda and the Rupnarain, eventually find an outlet through the Rupnarain into the Húgli; whilst only 35,000 cubic feet per second of the flood discharge of the Damuda flow along its channel past Ampta. || Assuming that the flood discharge given for the Rupnarain does not include any of the spill waters from the Damuda floods, the combined average yearly discharge of these two rivers may be estimated, from the above data, to amount to not less than 80,000 million cubic yards.

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* "Memorandum on the River Hooghly," by H. Leonard, Calcutta, 1864, p. 3.

† "Report on the River Hooghly," by Hugh Leonard, 1865, p. 6.

‡ "Memorandum on the River Hooghly," by H. Leonard, Calcutta, 1864, p. 3.

§ "Report on the Damooda-Roopnarain Survey," by O. C. Lees, Calcutta, 1890, pp. 7 and 8.

|| Ibid, pp. 7 and 22.

Fresh-Water Discharge of the River Húgli below Húgli Point.—The average yearly fresh-water discharge of the Húgli, which was estimated to amount to about 126,000 million cubic yards at Calcutta, is augmented by the discharges of the Damuda and Rupnarain, opposite Fulta and Húgli points, to 206,000 million cubic yards past Húgli Point. This discharge varies, according to the seasons and the floods of the tributaries, from a minimum of about 21,000 cubic feet per second, up to a possible maximum of about 1,350,000 cubic feeet per second, with all the tributaries simultaneously pouring down their maximum flood discharges.

The last two tributaries of the Húgli, the Haldia and the Rasulpur, flowing into the wide estuary, have comparatively little influence upon the navigable channel of the Húgli. The Haldia rises in the hills to the west of the Húgli, and drains a fair-sized basin; but the basin of the Rasulpur is quite small. The discharge of the Haldia has been estimated at 100,000 cubic feet per second during high floods, and one-fourth of this amount during the remainder of the rainy season,* which would give an average annual discharge of about 12,000 million cubic yards; and in the absence of any data about the Rasulpur, an average yearly discharge of about 2,000 million cubic yards is probably an ample allowance for this river, considering its small drainage area. This additional volume of fresh water introduced below Húgli Point raises the estimated annual fresh-water discharge of the Húgli at the mouth of the estuary, below the confluence of the Rasulpur, to an average of 220,000 million cubic yards.

Remarks on the Fresh-Water Discharge of the River Húgli.—The estimates of the fresh-water discharges of the Húgli and its tributaries given above, can only be regarded as very rough approximations, considering the scanty data available; but some sort of estimate is necessary in order to indicate the kind of relation the fresh-water discharge of the Húgli bears to its tidal flow, and for the purpose of obtaining some idea of the volume of alluvium annually carried down. The flood discharges of the Damuda and the Rupnarain have alone formed the subject of a careful investigation, with the object of seeking a remedy for the evils of their floods; but it would be very desirable, for the purpose of determining the physical conditions of the Húgli with greater precision, that the average discharges of all the feeders and tributaries of the Húgli, at different seasons of the year, should be ascertained as closely as practicable.

ALLUVIUM BROUGHT DOWN BY THE RIVER HÚGLI.

Reliable observations of the amount of alluvium brought down in flood-time by the feeders and tributaries of the Húgli, appear to be very deficient; and no information is available as to the relative proportions of sand and mud in this alluvium.

Observations and Estimates of the Alluvium in the River Húgli at Calcutta.—The volume of solid matter carried down in a year by the Húgli past Calcutta was estimated in 1861, by Mr. Longridge, at 39,000,000 cubic yards; † and this

* "Memorandum on the River Hooghly," by H. Leonard, Calcutta, 1864, p. 3.

† "The Hooghly and the Mutla," by J. A. Longridge, Proceedings of the Inst. C. E., vol. XXI, p. 15.

estimate was adopted by Mr. Leonard in his Memorandum and Report on the Húgli.* The above estimate was based on some observations made in 1842 by Mr. Henry Piddington, on the amount of silt held in suspension by the Húgli near the surface at Calcutta, in each month of the year, which furnished an average of about $1\frac{3}{10}$ cubic inches of silt in a cubic foot of water, or a proportion of 1 to 1,333 ; † and Mr. Longridge applied the monthly proportions of dried silt obtained by Mr. Piddington to the corresponding monthly discharges from the Ganges into the Nadia rivers. The proportions, however, of silt were deduced from only twelve samples of water, taken from the surface of the river at noon on the first day of each month of 1842, without any regard to the state of the tide when the sample was collected. The observations, therefore, very naturally exhibited anomalous results, showing the greatest proportion of silt in the river from March to June, with an average of 1 in 436, very probably due to the mud carried up by the strong flood tides at that period of the year, and by far the smallest amount in October, though the freshets are still at their height at the beginning of that month. The records of the weekly observations taken towards the end of the ebb tide, at the intake of the Calcutta Waterworks at Pulta, about 14 miles above Calcutta, during the last eleven years ‡ indicate, on the contrary, that the greatest amount of matter in suspension is carried down the Húgli in July and August when the flood discharge attains its maximum.

The amount of alluvium, moreover, in a river undoubtedly increases with the depth below the surface, down to the bottom, along which the heaviest particles are rolled by the current. Mr. Piddington, having had his attention directed to this circumstance, investigated a second set of samples of water taken from the Húgli, at Calcutta, from below the surface ; but he eventually arrived at results differing very little from those obtained by his first observations.§ Nevertheless, for facility of recollection, he adopted the proportion of 1 cubic inch of solid matter to 1 cubic foot of water in the Húgli, which has since been quoted as the accepted proportion of silt carried down by the Húgli ; ‖ and on this basis he estimated that, during the height of the floods, the Húgli brings down 257 cubic feet of solid matter per second past Calcutta, and 298 cubic feet per second past Moyapur. In dealing, however, with the supply of water to navigation canals in India from silt-bearing Bengal rivers, Mr. Apjohn from experiments made by himself and others on the waters of the Húgli and other Bengal rivers, deduced a ratio of increase in the amount of silt with the depth, ranging from 3·9 to 10 per cent. for each additional foot below the surface, according to the state of the river, as a river with a diminishing discharge is found to contain less silt in suspension than with a rising flood. ¶

* "Memorandum on the River Hooghly," p. 4, and "Report on the River Hooghly," p. 6.

† "On the quantity of silt held in suspension by the waters of the Hooghly at Calcutta, in each month of the year," by Henry Piddington, Journal of the Asiatic Society of Bengal, Calcutta, 1855, vol. XXXIII, p. 286.

‡ Copies of these records were supplied me, when in Calcutta, by Mr. James Kimber, then Engineer to the Corporation of Calcutta.

§ "A second series of experiments to ascertain the mean quantity of silt held in suspension by the waters of the Hooghly, as also the quantity carried to sea," by Henry Piddington, Journal of the Asiatic Society of Bengal, Calcutta, 1857, vol. XXV, p. 257.

‖ Proceedings of the Inst. C. E., vol. LIII, p. 18.

¶ "Navigation Canals in India," by J. H. Apjohn, Calcutta, 1895, p. 16.

Alluvium brought down from the Ganges by the Nadia Rivers.—The alluvium brought into the Húgli is evidently liable to vary in nature and proportion according to the source from which it is derived. Some experiments were made by Mr. C. G. Livesay, in 1893, on the amount of silt contained in the waters of the Bhagirathi near Murshidabad, at different depths and at different periods of the flood season, which are quoted by Mr. Apjohn in his Sibpur College lectures ;* and they afford a means of forming a rough estimate of the amount of alluvium brought down from the Ganges by the Nadia rivers. Applying the results of these experiments to the monthly discharges from the Ganges into the Nadia rivers, between June and November, given by Mr. Longridge,† the volume of silt in its wet condition brought down from the Ganges by the Nadia rivers during this period, amounts to 85,000,000 cubic yards, which is approximately equivalent to 44,000,000 cubic yards of dry silt.

The Ganges is densely charged with alluvium in floodtime, owing to the large quantity of detritus continually being formed by the attrition of the slopes of the Himalayas by glacier action, and by the slips resulting from the descent of avalanches, which is carried into the river on the melting of the snows and glaciers in summer. The alluvium carried along by the Ganges is also derived from the erosion of the land in the frequent changes in its channel during the floods, in traversing the vast alluvial plains, stretching from the base of the hills to its delta, which have been formed in the course of ages by the gradual deposit of the detritus, brought by the river from the hills, over the flooded valley. The Ganges is, consequently, the source of a large proportion of the alluvium carried down by the Húgli during the flood season. The proportion, however, of alluvium brought into the Nadia rivers from the Ganges, in relation to the volume of water, is probably materially less than the proportion carried down by the Ganges along its main channel past the inlets into the Nadia rivers, on account of the beds of these inlets being several feet higher than the bed of the Ganges, so that the heaviest alluvium of the Ganges, and the portion of the current near the bottom, containing the greatest burden of alluvium, are prevented from entering these rivers. The changes also in the sites of the inlets, and in their positions in relation to the main current of the Ganges, must occasion considerable variations in the amount of alluvium introduced each year into the Nadia rivers.

Alluvium from the Tributaries of the River Bhagirathi.—The sources and basins of the tributaries of the Bhagirathi, and also of the Húgli, are essentially different to those of the Ganges; for these rivers do not rise, like the Ganges, from very extensive glaciers terminating in large moraines, and followed by steep slopes down to the plains ; and they only traverse alluvial plains, for a comparatively short distance, in the lower portion of their course. Accordingly, the alluvium brought down by these tributaries must bear a much smaller proportion to their discharge than in the case of the inflow from the Ganges into the Nadia rivers, except possibly for a short period during the height of their brief floods. Assuming, therefore, in the regrettable absence of experimental data, that the ratio of alluvium to discharge, in the case of the tributaries of the Bhagirathi,

* Navigation Canals in India, by J. H. Apjohn, Calcutta, 1895, pp. 15 and 16.

† Proceedings of the Inst. C. E., vol. XXI, p. 14.

is only half of that of the inflow from the Ganges, the average volume of solid matter annually brought into the Bhagirathi by its tributaries may be estimated to amount to 16,000,000 cubic yards.

Alluvium carried past Calcutta.—Adding the above quantity to the previously estimated amount of alluvium brought down from the Ganges by the Nadia rivers, gives a total of 60,000,000 cubic yards as the estimated volume of solid matter carried down annually, on the average, by the Húgli past Calcutta. Deducting the volume of comparatively clear water, discharged during the dry season, from the calculated annual average discharge of the Húgli past Calcutta, the above volume of alluvium in relation to the discharge throughout the freshets, is equivalent to about $1\frac{1}{10}$ cubic inches of solid matter to each cubic foot of water.

Whilst the Ganges is doubtless the source of the largest proportion of alluvium introduced into the Húgli above Calcutta, owing to the disintegrating effects of the glaciers of the Himalayas and the instability of the channel of the Ganges, the matter thus introduced is in all probability in a finer state of division generally, and contains a considerably greater proportion of mud, owing to its trituration in the long distance traversed by the Ganges, and the height of the bottom of the inlets of the Nadia rivers above the bed of the Ganges, than the alluvium brought down by the tributaries of the Bhagirathi, which flow down with a much shorter course from hills of moderate elevation. The comparative fineness of the alluvium from the Ganges is confirmed by a comparison of the samples of sand collected by Mr. Norman from the Bhagirathi and its tributaries ; for the finest sand was obtained at the Naranpur inlet of the Bhagirathi ; and coarser sand was found near the outlets of the tributaries, especially in the Dwarka and Adjai, the largest of these affluents.

Alluvium brought down by the Rivers Damuda and Rupnarain.—Between Fulta and Húgli Point, the volume of alluvium in the Húgli is considerably increased by the addition of the alluvium discharged by the Damuda and Rupnarain in flood-time. This addition was assumed by Mr. Longridge, in his paper, to amount to 39,000,000 cubic yards annually, or the same as he had estimated was carried down by the Húgli past Calcutta, on the supposition that the combined discharges of the Damuda and the Rupnarain were the same in yearly volume as the discharge of the Húgli above their confluence, and that the proportion of alluvium to the discharge was the same in both cases.* From this Mr. Longridge concluded that the total quantity of solid material carried down the Húgli amounted to 78,000,000 cubic yards in a year ; and this quantity was adopted by Mr. Leonard in his report, with merely the qualification that "the quantity passing Calcutta is perhaps under-estimated, while that from the rivers south of Calcutta is perhaps over-estimated."†

As the general physical conditions of the Damuda and the Rupnarain are similar to those of the adjacent tributaries of the Bhagirathi, it may be fairly assumed, in the absence of any observations, that they bring down a similar

* Proceedings of the Inst. C. E., vol. XXI, p. 15.

† "Report on the River Hooghly," by Hugh Leonard, 1865, p. 6.

volume of alluvium in proportion to their discharge. Calculated on this basis, the quantity of solid matter brought down by these rivers would amount to about 30,000,000 cubic yards annually. As, however, a large portion of the flood discharge of the Damuda, in leaving the channel of the river and flowing over the intervening land into the Rupnarain, must deposit some of its heavier alluvium on the land in its course, the estimated volume of alluvium reaching the Húgli may safely be reduced to 25,000,000 cubic yards.

Alluvium discharged into the Estuary of the Húgli.—According to the above estimates, the quantity of alluvium carried down by the Húgli into its estuary amounts, on the average, to 85,000,000 cubic yards annually. Assuming that the Haldia and the Rasulpur bring down the same volume of alluvium in proportion to their discharges, as has been estimated for the other tributaries, their contribution of alluvium to the estuary of the Húgli amounts to about 5,000,000 cubic yards annually. This addition makes the total estimated amount of solid matter carried, on the average, every year into the Húgli by the fresh-water discharge, reach 90,000,000 cubic yards.

The proportion of alluvium to discharge, according to the foregoing estimates, amounts to 1 in 2,444 ; and if the clear flow in the dry season is deducted, the proportion is increased to about 1 in 2,000. The estimated proportion of alluvium to discharge arrived at for the Húgli, of 1 in 2,444, is rather less than the proportion of 1 in 2,166 obtained by observation for the Rhone, which rises in the glaciers of the Alps and has a considerable fall down to its delta. It is almost identical with the proportion of 1 in 2,420 arrived at for the Mississippi ; and it is considerably higher than the proportions estimated for the Danube and the Volga.

Remarks on the Estimate of Alluvium brought into the River Húgli.—For a due consideration of the conditions to which the Húgli is subject, it is important to obtain some notion of the average amount of alluvium brought into it every year by the fresh-water influx. The foregoing estimates, however, made with this object, are only rough approximations based upon meagre data, supplemented by a consideration of the general physical features of the basins of the tributaries as compared with the Ganges. In order to obtain the amount of this alluvium with precision, observations would be required of the amount of material contained in the waters of the feeders and tributaries of the Húgli, and also in the Húgli itself, at various periods during the descent of the freshets, and at different depths, for at least three or four flood seasons, on account of the variations in the rainfall and of the inlets from the Ganges from year to year.

Nature of the Alluvium found in the Rivers Húgli and Bhagirathi.—The alluvium in the Húgli consists essentially of mud and sand, the fine mud being readily carried in suspension by the current of the river, and borne up and down by the flood and ebb tides ; whilst the sand, being less easily transported, settles more or less readily when the current slackens, in proportion to its coarseness. The mud forms a very conspicuous feature in the Húgli during the freshets, and even to some extent in the dry season, especially during strong spring tides in the estuary, when no alluvium is being brought down from inland, owing to its

being so easily kept or put in suspension by the freshets and tides. This mud, however, though depositing in still water in creeks, recesses, back waters, and shallows, is for the most part carried out to sea, where it is dispersed by currents and waves, or settles during slack tide and calm weather in deep water where a muddy bottom is found ; and only under exceptional circumstances does it constitute any portion of the shoals obstructing navigation.

An examination of seven samples of sand collected by Mr. Norman from the bed of the Bhagirathi, its two principal tributaries, and the Húgli at Nadia, and of fourteen samples obtained by Captain Petley from the bars and other parts of the bed of the Húgli, betwen Calcutta and the sea, gave the following results : The bed of the inlet of the Bhagirathi at Naranpur consists of clean, fine, grey sand ; and clean sand was found in the Bhagirathi at Kanupur, Laltakuri, and Katwa, and near the mouths of the Dwarka and Adjai, varying from rather fine, brownish grey sand at Kanupur and Laltakuri, to coarse brown sand in the Adjai. The sands in the Bhagirathi at Katwa and in the Húgli at Nadia, appear to consist of a mixture of the fine grey sand from the Ganges with the coarse brown sand from the Bhagirathi tributaries, in which the grey Ganges sand very distinctly predominates, confirming the view previously expressed that the alluvium from the Ganges is larger in volume and finer in quality than the alluvium from the Bhagirathi tributaries.

Though there is mud on the foreshore of the river in the recess of the jetties at Calcutta, there is not a trace of mud on the sandbanks at Hastings, Fulta, and Húgli Bight, or on the Moyapur and Balari bars and the James and Mary sands ; and the sands at these places are all quite clean and brownish grey, resembling for the most part the sand found at Nadia, though generally more grey and somewhat finer, the most brown and finest sand being found at Moyapur, and the nearest approach to the sand at Nadia being met with at Balari, though somewhat finer. The brownish sand of the Haldia bar contains some admixture of silt, derived no doubt from the mud discharged from the Haldia during the freshets and from the erosion of the western shore above Haldia Point. This mud, brought into the Haldia by the strong flood tides of the Húgli at springs, during the prevalence of the south-west monsoon during the dry season, has accumulated considerably in the last few years, owing to the reclamation of low-lying lands along the banks of the Haldia, whereby the tidal scour in this river has been materially diminished.* The sands of the Jellingham-Dredge and Eden bars are quite clean, like the sands of the bars above the mouth of the Haldia ; the sand of the Jellingham-Dredge bar is the finer and greyer of the two, and is very similar to the sands of the James and Mary shoal ; whilst the sand of the Eden bar resembles the sand of the Moyapur bar in colour, and of the Balari bar in general size of particles, though containing more coarse particles very similar in appearance to the coarser particles in the sand found near the mouth of the Adjai, a short distance above Katwa. The sand of the Middleton bar contains a slight admixture of silt, and has a slight greenish tinge in its light brown colour, which is more marked in the silty sand of the Haldia bar; but in other respects it is

* "Navigation Canals in India," by J. H. Apjohn, Calcutta, 1895, pp. 11 and 12.

very similar to the sand of the Balari bar, though somewhat coarser.* The silt in the sand of the Middleton bar is probably due to the erosion which is taking place all along the southern portion of Saugor Island, and the facilitating of deposit from the silt-laden current, during slack tide, in emerging from the estuary into the open sea to the south of Saugor Island.

Clean sand is found on the bed of the Húgli in the Buj-Buj, Fisherman's Point and Kulpi anchorages, the sand in the two first places being very similar to the sands of the Húgli Bight and Balari bar; whilst the sand of the Kulpi anchorage is somewhat coarser and browner. Mud, however, constitutes the bottom of all the anchorages in the estuary below Kulpi, of the deep Eastern Channel forming the navigable outlet, and of the sea some miles further out. The mud found in the bed of deep hollows in the estuary, such as Saugor Roads, may be attributed to local scour, removing the sand and laying bare an old muddy stratum deposited in deep water when the surrounding conditions were different; for in the absence of scour, these hollows would be rapidly filled up towards the close of the flood season, by the heavier alluvium brought down the river. The mud found in deep water in the bed of the Eastern Channel, and in the sea beyond, is no doubt due to the deposit of a small portion of the muddy alluvium brought down by the river or eroded from the shores, in calm weather during slack tide, under specially favourable conditions.

The mud, accordingly, which constitutes a large portion, and by far the most noticeable material of the alluvium of the Húgli, has hardly any influence in producing impediments to navigation. The portion of the alluvium which is really of importance with regard to the navigable condition of the Húgli, is the sand which is liable to deposit in the river and estuary, and forms the banks and bars which deflect and shoal the navigable channel. It is therefore very desirable that the proportion of sand contained in the alluvium carried down the Húgli by the freshets should be ascertained.

TIDES OF THE RIVER HÚGLI.

Rise of Tide in the River Húgli between the Sea and Calcutta.—The tide in the Bay of Bengal, in front of the mouths of the Ganges, rises in different parts from 9¼ to 11 feet at the height of ordinary springs, attaining its greatest range of 11 feet at the entrance to the Eastern Channel, which forms the navigable approach to the Húgli; and the range of neaps at the same point is 4 feet 6 inches.† The tidal range gradually increases, in converging to the Húgli estuary and ascending the narrowing channel. At Dublat, near the south-east corner of Saugor Island, the mean range of greatest ordinary springs is 14 feet 2½ inches; and the highest spring tides in each month, throughout the year, have an average range of 16 feet, and the lowest neap tides 3 feet 9 inches. At Diamond Harbour, the mean range of greatest ordinary springs is 15 feet 9½ inches, the maximum monthly range averages 17 feet 8 inches, and the minimum 5 feet 9 inches; whilst at Kidderpur, Calcutta, the mean range of greatest

* Specimens of all these sands are kept in the Deputy Conservator's Office at Calcutta.

† "Tide-Tables for the River Hooghly," Calcutta, 1896, p. 7.

ordinary springs is 11 feet 8½ inches, and the maxima and minima tides in each month average 12 feet 9½ inches and 5 feet respectively.

Spring Tides during the Dry Season in the River Húgli.—An inspection of the tidal diagrams of the 30th of March, 1896, Plate 1, Figs. 6 and 7, shows that the reduction in tidal range at Kidderpur during the dry season is almost wholly due to the rise inland of the low-water line, as high-water of the above tide was higher at Kidderpur than at the tidal stations lower down the river, with the exception of Balari, where the tide rose 3 inches higher. The high-water line, however, falls on ascending the Húgli above Kidderpur, so that high water on that day was 2 feet 2 inches lower at Noaserai than at Kidderpur, and 2 inches lower at Nadia than at Noaserai, making a total fall of 2⅓ feet between Kidderpur and Nadia. The rise of tide at Nadia on that day was a little over 2 feet; and the tidal influence at high spring tides during the dry season extends about 5 miles above Nadia, or about 84 miles above Calcutta, and 181 miles from the mouth of the Húgli. The fall of the high-water line above Calcutta shows that the tide is impeded in its flow up the river between Calcutta and Noaserai; and the loss of tidal scour at high springs from this cause is considerable, especially in the upper reaches of the river with the diminution in tidal range, so that at Nadia the tidal range at springs is only half what it would be if the tide rose to the same level there as at Kidderpur.

The opposition to the influx of the tide along the upper part of the Húgli is also manifested by the appearance of a bore at high spring tides in the dry season, which, commencing near Moyapur, reaches a maximum at Chinsurah, and only disappears above Noaserai, Plate 1, Figs. 6 and 7. The bore on the 30th of March, 1896, had a height of nearly 4 feet at Buj-Buj and Calcutta, increasing to a little over 4 feet at Konnagar, and to 5⅓ feet at Chinsurah, and then falling to about 18 inches at Noaserai. The shoals and sharp bends in the river appear to be the causes of the checking of the progress of the flood tide, which results in the fall of the high-water line and the creation of the bore.

Neap Tides during the Dry Season in the River Húgli.—The range of neap tides during the dry season increases from the mouth of the Húgli to a maximum near Húgli Point, whence it decreases somewhat towards Calcutta, the low neap tide of the 21st of March, 1895, Plate 1, Figs. 10 and 11, exhibiting ranges of 3 feet 3 inches at Saugor, 6 feet 1 inch at Húgli Point, and 5 feet 5 inches at Kidderpur. The increased range from Saugor up to Húgli Point was mainly due to a fall of the low-water line inland, of 2 feet 5 inches, between Saugor and Húgli Point; for after a rise of 5 inches, in the particular tide under consideration, from Saugor to Khijiri, the high-water line was practically level from Khijiri up to Kidderpur.

Mean Tide during the Dry Season in the River Húgli.—The fairly mean tide observed on the 8th of May, 1896, Plate 1, Figs. 4 and 5, exhibits, like the neap-tides, an increase in range between Khijiri and Húgli Point, followed by a reduction between Húgli Point and Kidderpur, the ranges at these places being 7 feet 3 inches, 8 feet 5 inches, and 6 feet 1 inch, respectively; and the low-water line of that tide shows a fall inland of 10 inches between Khijiri and Húgli

Point. The high-water line, however, on this occasion, instead of being almost level from Khijiri to Kidderpur, as in the neap-tide of the 21st of March, 1895, had a rise of 6 inches from Khijiri to Balari, followed by a fall of 10 inches from Balari to Buj-Buj, and then a rise again of 5 inches from Buj-Buj to Kidderpur. There was a fall in the high-water line of this mean tide up the river above Calcutta, as noticed in the spring-tide of the 30th of March, 1896, amounting only to 5 inches in this case at Noaserai, on account of the smaller range of tide. This tide appears to have reached Nadia, where a rise of 1 foot 1 inch was observed.

Spring Tides during the Freshets in the River Húgli.—The very large fresh-water discharge of the Húgli during the rainy season has very little influence on the tidal range in the estuary up to Húgli Point during spring tides, as the high-water and low-water lines are both raised from one to two feet above their levels of the dry season ; but the amount of tidal water passing up the river is reduced in proportion to the volume of fresh water coming down the river throughout the duration of the flood tide. Above Húgli Point, the influence of the freshets in checking the tidal influx, even at springs, becomes much more marked in the comparatively narrow channel ; and in ascending the river, the tidal rise becomes more and more a backing up of the fresh-water discharge, so that at Calcutta the downward current is only occasionally reversed at high springs during the height of the freshets. The rise of the high-water line, however, above Moyapur right up the river to the limit of the tidal observations of the 12th of August, 1889, at Dumardaha, two miles above Noaserai, compensates to some extent for the increased slope of the low-water line resulting from the freshets coming down the river, so that the range of tide at high springs is only reduced between one and two feet by the flood waters up to Calcutta, Plate 1, Figs. 8 and 9. The increasing slope of the low-water line in the narrowing channel above Calcutta, during the freshets, reduces the rise of high spring tides at Noaserai to about half their rise in the dry season, which amounted to only 2 feet 5 inches at Dumardaha on the 12th of August, 1889; whilst the tidal influence probably ceased about 7 miles higher up, or about 141 miles from the mouth of the Húgli, and forty miles below the tidal limit of the dry season.

Comparing the simultaneous tidal lines at springs in the dry and rainy seasons, Plate 1, Figs. 7 and 9, the raising of the low-water line by the freshets amounted to 1 foot 7 inches at Khijiri, 1 foot 10 inches at Balari, 2 feet 1 inch at Húgli Point, 3 feet 7 inches at Moyapur, 5 feet 6 inches at Kidderpur, 10 feet 8 inches at Chinsurah, and 12 feet 10 inches at Dumardaha ; whilst the high-water line, at the same period, was raised 10 inches at Khijiri, 1 foot 7 inches at Balari, 1 foot 10 inches at Húgli Point, 2 feet 4 inches at Moyapur, 3 feet 10 inches at Kidderpur, 7 feet at Chinsurah, and 8 feet 10 inches at Dumardaha.

Neap Tides during the Freshets in the River Húgli.—The chief influences of the freshets on neap tides in the Húgli are manifested by a raising of the low-water line, and a reduction in the tidal range, as compared with the dry season. Comparing the neap tides of the 21st of March and 27th of September, 1895,

Plate 1, Figs. 10 to 13, the raising of the low-water line in the freshets amounted to 1 foot 8 inches at Saugor, 3 feet 1 inch at Khijiri and Balari, and 5 feet 5 inches at Kidderpur ; whilst the range of the September tide, which was 3 feet at Saugor and reached a maximum of 5 feet at Moyapur, was less than the March tide by 1 foot 8 inches at Khijiri, 1 foot 2 inches at Húgli Point, only 8 inches at Moyapur, and 1 foot 9 inches at Kidderpur. Even during the freshets, there is a fall in the low-water line inland between Saugor and Húgli Point, which is followed by a rise to Kidderpur ; and there is a smaller rise in the high-water line between Húgli Point and Kidderpur, Plate 1, Fig. 13. Low-water of a low neaptide at Kidderpur is raised by the freshets to about the level of high-water of a similar tide in the dry season.

The fairly high neaptide of the 16th September last, which was observed at a series of stations between Khijiri and the tidal limit, furnishes somewhat similar indications ; for the high-water line after rising 9 inches from Khijiri to Balari, remained nearly level from Balari to Moyapur, and then rose with a gradually increasing inclination up to Satgachia, 140 miles above Khijiri, which was close to the limit of the tidal influence on that day, Plate 1, Figs. 14 and 15. The low-water line, which had a fall from Khijiri to Húgli Point of 9 inches, rose from thence, with the increasing slope due to the freshets, up to the tidal limit ; and the rise of tide which was 6 feet 6 inches at Khijiri, increased to 7 feet 2 inches at Húgli Point, and then decreased to 5 feet 11 inches at Kidderpur, 2 feet 3 inches at Noaserai, and only 3 inches at Satgachia.

The reduction in the range of neaptides in the Húgli during the freshets, does not by any means adequately indicate the diminution in the tidal influx at neaps during the rainy season ; for owing to the large volume of fresh water passing down the river at the height of the flood season, the rise of tide in the upper part of the estuary and in the river above, at low neap tides, is wholly due to the backing up of the freshwater discharged when the current is checked by the flood tide coming into the estuary.

Tidal Currents in the River Húgli. —The strength of the tidal currents varies in different parts of the river, and at different seasons of the year. The currents have least force during the prevalence of the north-east monsoon from November till February, having a velocity at springs of 3 to $3\frac{1}{2}$ knots an hour, and at neaps of $1\frac{1}{2}$ to 2 knots an hour.* During the latter part of the dry season, the south-west monsoon blowing in the direction of the flood tide increases its velocity, so that it flows up the river at the rate of from 4 to 6 knots an hour during springs from March to June. The descent of the freshets from July to October causes the ebb tide to predominate, reaching a maximum velocity at that period during springs of 6 knots an hour ; whilst the current of the flood-tide is almost obliterated, except in the estuary. Accordingly, as regards the tidal currents in the Húgli, there are three distinct periods in a year, lasting approximately for four months each. During the cold season, the flood tide current has a slight preponderance over the ebb tide current, owing to its shorter

* "Survey of the River Hooghly from Calcutta to Saugor Point," by Commander Richard Lloyd, R. N., 1836, Note.

period of flow ; during the second half of the dry season, the flood tide is considerably stronger than the ebb tide, being propelled by the south-west monsoon ; whereas during the rainy season, the flood tide is overpowered by the descent of the freshets, which gives a great predominance to the ebb tide.

TIDAL FLOW INTO THE RIVER HÚGLI.

The tidal capacities of the Húgli above the confluence of the Rupnarain, and the Damuda and Rupnarain, given by Mr. Leonard in his report,* afford no indication of the actual volumes of tidal water entering these channels, for they are never completely filled up to the high-water line ; whilst no reference was made in the report to the tidal capacity of the estuary of the Húgli.

Flow of Spring Tides in the Dry Season into the River Húgli.—In every tidal river the tide necessarily takes a certain time in passing up the river, so that it begins to fall near the outlet before high tide has been attained far up the river ; and the further the tidal portion of the river extends, the less completely is it filled each tide. Taking the tide of the 30th of March, 1896, the tidal diagrams show that when it was high-water at Khijiri, it was low-water at Kidderpur ; and high tide was not attained at Nadia till about 10½ hours after high-water at Khijiri, which is equivalent to 11 hours after high-water at Dublat, Plate 1, Figs. 6 and 7. The flow of the tide into the Húgli is, indeed, limited to the period during which the tide is rising at the mouth, and for a short time after, as the inflowing current is not immediately reversed when the tide begins to fall outside. Moreover, as the water is still flowing down higher up the river when the tide is rising at the mouth, a portion of the tidal rise, even in the dry season, is produced by the backing up of the latter part of the ebb in the river above. The influx, therefore, into the Húgli during a tide is fairly represented by the volume of water comprised between the simultaneous tidal lines corresponding to high-water and low-water at Khijiri, spread over the area of the estuary and river up to where the two lines intersect, less the volume of fresh water coming down the river during the period of tidal rise at Khijiri. The seaward portion of the tidal water entering the estuary flows out again to sea on the turn of the tide ; whilst the inner portion flows up the estuary and into the river in proportion to the tidal capacity, and raises progressively the water-level of the river, till at last during spring tides, in the dry season, high tide is propagated up to the tidal limit, about 5 miles above Nadia. At the time of high-water at Nadia, with a tide like that of the 30th of March, 1896, Plate 1, Figs. 6 and 7, the following tide has entered the estuary, and has risen within 5 feet of high-water at Khijiri and above half tide at Balari, and has commenced to rise at Húgli Point ; and high-water of the succeeding tide is reached at Saugor within an hour and a half of high tide at Nadia.

Calculating the tidal influx into the Húgli on the basis stated above, and making an allowance for the tidal flow up the Rupnarain and Damuda, the volume of water entering the Húgli at a high spring tide, in the dry season, has been found to amount to about 4,826 million cubic yards, which, with a tidal flow of 5½ hours, is equivalent to an influx of 244,000 cubic yards per second, or rather

* "Report on the River Hooghly," by Hugh Leonard, 1865, p. 11.

more than four and a half times the maximum fresh-water discharge at the highest floods. The volume of tidal influx, however, is reduced in passing up the river, owing to the reduction in the available tidal capacity, especially after leaving the wide estuary and entering the comparatively narrow river above Húgli Point; and it has been estimated that the tidal influx, during a high spring tide in the dry season, past Calcutta, would only amount to 14,000 cubic yards per second.

Though no more tidal water can enter the river from the sea after the tide has fallen sufficiently to reverse the current at the mouth, nevertheless, the propagation of the tidal flow up the river, and the distance to which the tidal influence extends, and consequently the power and extent of the tidal scour in the channel, and the range of influence of the tidal oscillation in preventing the deposit of suspended matter, depend upon the facility the condition of the river affords for the upward passage of the tidal flow.

Flow of Spring Tides during the Freshets into the River Húgli.—The increase in the volume of water in the estuary and up the river to a little above Buj-Buj, during the rise of a high spring tide at Khijiri, is somewhat larger at the height of the freshets than during the dry season, as indicated by a comparison of the differences in level between the simultaneous tidal lines corresponding to high-water and low-water near the outlet in the diagrams of the March and August tides, Plate 1, Figs. 7 and 9. For a high spring tide, corresponding to that of the 12th of August, 1889, the increased volume in the river between the levels of the simultaneous tidal lines at low-water at the mouth and high-water at Khijiri, has been calculated to amount to 5,150 million cubic yards, which is equivalent to a flow of about 260,000 cubic yards per second. The maximum fresh-water discharge of the Húgli, with all the tributaries in high flood, has been estimated at about 1,450,000 cubic feet, or 54,000 cubic yards per second. Accordingly the influx of tidal water at Saugor during a high spring tide at the height of the freshets, is not less than about 206,000 cubic yards per second, or nearly four times the maximum fresh-water discharge. On proceeding, however, up the estuary, the tidal influx diminishes rapidly; whilst the fresh-water discharge experiences only a slight reduction up to Húgli Point, so that even at this part of the river, with a high flood discharge from all the tributaries, the tidal rise consists practically in a backing up of the fresh-water discharge during flood tide in the estuary. At Calcutta, during the highest period of the freshets, the downward current is merely checked by the flood tide, even at high springs, for the increase in the volume of the water in the river above Kidderpur during the tidal rise there, which lasts about three hours, is less than half the amount of the maximum fresh-water discharge during the same period.

Flow of Neap Tides into the River Húgli.—By aid of the tidal diagrams for the 21st of March, 1895, compiled from the tidal records, Plate 1, Figs. 10 and 11, the volume of tidal water entering the Húgli at Saugor at a low neap tide during the dry season, has been calculated to amount to about 1,470 million cubic yards. As the flood tide at Saugor continues for 5½ hours, the above volume is equivalent to an influx of about 74,000 cubic yards per second during this period.

During the rainy season the aetual increase in the volume of water in the river during the rise of tide at the mouth at low neaps, is less than in the dry season; and when the freshets are at their height, about three-fourths of this increase is due to the backing up of the land waters. Nevertheless, even when a low neap tide eoineides with a high flood discharge, some tidal water flows into the lower part of the estuary; and the ebb tide, being reinforced throughout its duration by the large fresh-water discharge, has a mueh greater scouring influenee than in the dry season.

Remarks on the Tidal Flow into the River Húgli.—The tidal flow into the Húgli during the four months of the dry season that it runs strongest, owing to the prevalence of the south-west monsoon, amounts altogether to more than double the total fresh-water discharge in a year. Throughout the rainy season some water enters the Húgli from the sea at every tide, owing to the wide expanse of the estuary, even at the lowest neaps; and on account of the good influx at high springs, Plate 1, Fig. 9, the volume of water entering the estuary during this period is not much less than in a similar period of the dry season. Above the estuary, however, where the comparatively narrow channel of the river affords a much smaller area for the influx of the tide, and is filled by fresh water at the height of the freshets, the tidal influence becomes insignificant throughout the rainy season; but during the rest of the year, the flood and ebb tides are practically the only forces affecting the river and estuary; and they exercise their influences on the Húgli throughout its entire length between Nadia and the sea.

TIDAL CONDITION OF THE RIVER HÚGLI.

The wide mouth of the estuary, and its gradual contraetion in width inland, render the tidal condition of the Húgli quite satisfactory up to Húgli Point (with the sole exception of a slight fall of the high-water line from Balari to Húgli Point), where, in spite of the sandbanks eneumbering the estuary, the contraction of the estuary at Kulpi, and its enlargement again above at Diamond Sand, the range of high spring tides is only an inch less than at Balari, and greater than at Khijiri and Saugor, Plate 1, Figs. 6 and 8. Moreover, the range of neap-tides at Húgli Point is greater than at any other tidal station, Plate 1, Figs. 10 and 12. Above Húgli Point, the tidal range is reduced up to Moyapur, merely by the rise of the low-water line; but there is a fall of 6 inches in the high-water line of the 30th of March, 1896, between Moyapur and Buj-Buj, indicating a checking of the floodtide in passing round the Achipur bend and the Buj-Buj Sand. The fall, however, of the high-water line at Buj-Buj, on that occasion, was more than regained by a rise from thence up to Kidderpur of about 9 inches; but an interference with the tidal influx in this part of the river is also indicated by the appearance of the bore at spring-tides in the dry season. The fall in the high-water line from Caleutta to Noaserai in the dry season shows that this portion of the river presents obstructions to the progress of the flood tide, for under favourable conditions the tide should rise as high at Nadia as at Calcutta; and the unsatisfactory condition of the channel is further proved by the increase in the height of the bore up to Chinsurah, and its continuation up to Noaserai, Plate 1, Figs. 6 and 7. Observations similar to those from whieh the tidal diagrams of

the 30th of March last have been drawn out, might be made with advantage at intervals of five or ten years, at the same stations, and under as nearly as possible identical conditions of tide, so that any variations in the tidal condition of the river, between the mouth of the river and the tidal limit, may be ascertained. An increase in the fall of the high-water line inland, and a raising of the low-water line, would indicate a deterioration in the channel, and a loss of tidal scour; whereas a reverse effect would prove that the channel had become freer from obstructions, and that the tidal condition had improved.

INFLUENCES OF THE TIDE ON THE RIVER HÚGLI.

Favourable Influences of Tidal Action.—If no tide existed in the Bay of Bengal, the Húgli would resemble the branches of the Danube and the Mississippi traversing their deltas, and would extend in a comparatively narrow channel to the sea; and a high bar would be formed in front of the outlet by the deposit of all the heavier sediment brought down by the freshets, preventing the entrance of vessels of large draught. The existence, on the contrary, of an expanding estuary, and a wide mouth devoid of a bar in front of sufficient height to form a permanent barrier to large ocean-going vessels, is due to the tidal flow and ebb, which, being derived from an unlimited supply, are capable of maintaining a wide outlet, and by their constant oscillation up and down disperse the alluvium brought into the Húgli during the rainy season. Moreover, during about two-thirds of the year, the tide is alone available for maintaining the channels and providing an adequate depth of water for navigation. Even during the rainy season, the favourable influences of the tide, though considerably restricted, are not by any means obliterated; for the flood tide by backing up the land waters for a time, increases the scouring efficiency of the ebb tide; and the flow and ebb of the tide, which still continue in the estuary at the height of the freshets, prevent the accumulation of the alluvium, brought down by the river, just in front of the outlet, which invariably occurs in the case of silt-bearing rivers flowing into tideless seas.

Unfavourable Influences of Tidal Action.—As the incoming flood tide predominates over the ebb tide throughout the dry season, and especially during the prevalence of the south-west monsoon, which increases its strength, more material must be carried up the river by the flood tide from the sandbanks and shoals at the outlet and in the estuary, and from the erosion of the banks, than is taken down again by the ebb tide. The river, accordingly, would gradually silt up if it was not periodically scoured out by the descent of the freshets. The flood tide, moreover, coming from an opposite direction to the ebb tide and fresh-water discharge, runs up generally along the opposite side of the river to that followed by the navigable ebb channel, and forms secondary, though generally, blind channels in the sandbanks projecting from the convex bank in the bends of a river, where the width between the banks has been increased by the erosion of the concave bank by the freshets, aided by the ebb tide at high springs. Numerous instances of this action of the flood tide, during the dry season, are observable at the bends of the Húgli, notably at the Diamond, Brul, Buj-Buj, Sankral, and Ghusri sands, and the Dakinshur, Kutrang, Bullubpur,

and Barrackpur flats above Calcutta ; whilst the obstacles to navigation at the James and Mary and Moyapur shoals are also due to the formation of channels by the flood and ebb tides along opposite sides of the river, leaving a central shoal between them, Plate 2, Figs. 1, 2, 4 and 5, and Plate 9. Flood-tide channels, shoaling at the upper end, are also discernible in the estuary, the most marked of which are the Bedford Channel and the Central Channel running up between the Upper Long Sand and the Mizen Sand ; whilst the channel at the back of Saugor Island appears to be similar in character.

Value of Tidal Action in the River Húgli.—The advantages of tidal action in the Húgli, in dispersing the alluvium brought down from inland, and in providing water for navigation over the shoals at high tide during two-thirds of the year, evidently much more than counterbalance the antagonism between the action of the flood and ebb tides, as well as a certain amount of change in position of the navigable channel, according as the freshets or the flood tides have the predominance. Moreover, the existing natural condition of the Húgli, when contrasted with the condition of the outlets of the Mississippi and the Danube before any works were carried out, with navigable depths over the bars in front of their outlets of only 13 feet and 8 feet, respectively, sufficiently attests the value of tidal flow for the navigation of the Húgli, especially considering that the ratio of the maximum to the minimum fresh-water discharge, which is 4 to 1 for the Mississippi and 8 to 1 for the Danube, amounts to at least 13 to 1 in the Húgli at Calcutta. Consequently, every effort should be made to maintain the tidal condition of the Húgli in as satisfactory condition as possible ; and in all works carried out on the river, any checking of the tidal influx should be carefully guarded against.

CONDITION OF THE NAVIGABLE CHANNEL OF THE RIVER HÚGLI.

The Húgli may be divided into two portions, namely, the river proper from Nadia to Kantabaria, and the estuary from Kantabaria to the mouth beyond Saugor Island, Plate 1, Fig. 3. The navigable channel in the river is tolerably stable, with only such annual variations as are caused by the difference in direction of the scour of the freshets and the flood tide respectively during the rainy and dry seasons ; whilst the channel through the estuary is subject from time to time to changes across the whole width of the estuary, such as occur in all wide, sandy, tidal estuaries in their natural condition, Plate 9, Fig. 2. As the river traverses throughout the alluvial delta formation of the Ganges, and makes a series of bends like all rivers passing through flat alluvial plains, there are considerable differences in depth along the course of the main channel, as indicated in the longitudinal section of February, 1896, Plate 3, Fig. 14. Nevertheless, there was a minimum depth, at low-water, of spring tides in February last, of 27 feet between Calcutta and the Moyapur shoal, and of 20 feet between Moyapur and the James and Mary shoal, which was also the minimum depth from Calcutta nearly up to Barrackpur, at the end of 1885, the date of the last survey, Plate 2, Fig. 3. Below the James and Mary shoal to the entrance of the estuary at Kantabaria, and a short distance beyond to the Kulpi anchorage,

the depth is considerable throughout. Below the Kulpi anchorage, however down to Saugor Roads, the navigable channel through the estuary becomes much more uniform in depth, ranging for the most part between 30 and 15 feet below low-water of spring tides. There are four places in the estuary where the depth in the navigable channel is generally a little less than 3 fathoms at low-water of spring tides, known as the Balari, Haldia, Jellingham-Dredge, and Eden bars, with a variable width between the 3 fathom lines of soundings, Plate 10. A deep hollow exists in the channel, just above Saugor Lighthouse, extending from the upper part of Saugor Roads towards the Bedford Channel, and skirting Saugor Flat, with a depth of from 7 to nearly 10 fathoms at low-water of springs. From Saugor Roads, the outlet channel gradually shoals seawards to the Middleton Bar, over which the depth is reduced to a little under 3 fathoms, beyond which the Gaspar Channel is reached, leading to the deep Eastern Channel, and thence out to sea.

The Moyapur and James and Mary shoals are the only bars of any consequence at the present time in the Húgli between Calcutta and Kantabaria; but owing to the small available depth of water over these shoals at some periods, they occasionally constitute very serious obstacles to the passage of vessels of large draught. The five bars across the navigable channel in the estuary and at its outlet are, on the whole, considerably wider than the bars in the river above; but, on the other hand, they are lower, and the navigable channel over them is broader. Accordingly, although the bars in the estuary are a source of much greater anxiety to the river surveyors, owing to their uncertain, shifting character, than the Moyapur and James and Mary bars, the general variations of which with the seasons are well known, nevertheless the pilots regard these upper shoals as far more serious impediments to the safe and expeditious navigation of the river. This opinion is due, not merely to the decidedly smaller and more variable depth of water over these upper bars, but also to the small width of the navigable fair-way across these shoals, the cross currents experienced at some points, and the distance of these shoals from the outlet, which prevents vessels which, in passing down the river, have been obliged to cross the James and Mary shoal at the top of the tide, from getting far down the river before the tide has fallen too low to afford them a sufficient depth of water for passing over the bars below.

II.—Changes in the River Húgli.

There are three kinds of changes which might take place in a river subject to such conditions as the Húgli, two of which undoubtedly do occur in the Húgli, and the third of which alone requires investigation. *Firstly*, there are periodical changes produced, according to the seasons, by the freshets and the flood tide successively. *Secondly*, there are variable changes due to variations in the yearly rainfall, and in the position and sizes of the inlets of the Nadia rivers from the Ganges; and there are also constant changes going on in the navigable channel through the estuary of uncertain duration and extent, as well as in the general depths in the estuary, and the position and size of the sand-banks. *Thirdly*, there are permanent changes resulting from the continuous

action of certain causes, such as an increase in the sinuosities of a river by the erosion of the concave banks, an enlargement in width of a river or estuary by the erosion of the banks by currents or waves, and the shoaling of the channel of a river, or accretion in an estuary, by the progressive deposit of alluvium. The first kind of change is manifested by the different states of the channels at the Moyapur crossing, and in the James and Mary Reach during the rainy and dry seasons ; and the second kind of change is demonstrated by a comparison of the surveys of the estuary at different dates. These changes, however, though of importance in considering the improvements expedient for navigation, do not of themselves afford any evidence of a deterioration in the condition of the Húgli. Permanent changes, with progressive alterations always in a definite direction, without any signs of a reversal of the action and of a return to a former condition, are the only movements which indicate definitely a deterioration or improvement in the state of a river, though they are liable to be masked by periodical and variable changes, the existence of which renders permanent alterations more difficult to distinguish with certainty.

Opinions on the Deterioration of the River Húgli.—The first recorded opinions on the question of the deterioration of the Húgli appear to have been those of the members of the Committee, appointed in 1853 by the Government of Bengal, at the request of the Bengal Chamber of Commerce, to inquire into the state of the Húgli, and particularly whether it had deteriorated, and the cause, nature, and progress of this deterioration. In their report, presented in 1855, Captain D. Robertson and Mr. J. J. Mackenzie stated that the channels between Calcutta and Khijiri were, "on the whole, about the same as in the beginning of the present century;" but that "the same character cannot be applied to the channels below Kedgeree. The preponderance of evidence decides that they have deteriorated, and that they have gone more to the south."* They, moreover, remarked that, "It is very difficult to understand how a river, into the channels of which, like the Húgli, such enormous quantities of earthy matter are annually poured and deposited, can do otherwise than deteriorate (if totally left to its natural agencies), however gradual or slow the process may be ;" and they added that the records of the good state of the river in 1774 and 1776 along the channel passing Fulta Sand, through the Eastern Gut of the James and Mary Reach, and from Khijiri to the sea, "would seem to indicate a much more important deterioration than the experience of any of the witnesses leads them to admit." They summed up the conclusions they had arrived at from the evidence submitted to them, by the statement "that the River Húgli has deteriorated up to the present time, that deterioration has been gradual, and caused by the shoaling and contraction of its deep channels by the accumulation of silt, and that under the present conditions of the river the deterioration will be progressive." Lastly, after expressing their inability to form any idea as to the period when, owing to this continued deterioration, "ships of large burden may be expected to resort by preference to the "Mutlah," they urged, "looking to the immense interests that would be most "injuriously affected by such an event, that every means should be taken to

* "Reports with Proceedings and Appendix of the Committee appointed by Government to enquire into the state of the River Hooghly," Calcutta, 1854, p. 15.

"avert such a catastrophe; and the highest hydraulic engineering skill should be "called in."*

The third member of the Committee, Mr. H. Piddington, dissenting from the views of his colleagues, presented a separate report, in which he stated his opinion, "that up to the close of the year 1853, there is no fair ground for sup-"posing that the Húgli has, upon the whole, deteriorated from Calcutta to the sea, "as a navigable river, during the present century."† He further observed, and I "fully concur in the view taken by so many of the best informed of the witnesses, "that as one channel shuts up another opens out; so that I find nothing to lead us "to anticipate any future deterioration, beyond such as may arise from a temporary "shallowing of some of the difficult channels, while a change is going on near it, "as exemplified annually in the alternate closings and openings of the Eastern and "Western Guts of the James and Mary."

In a report on the rivers of Bengal, in 1857, Captain Sherwill referred to the belief that the Ganges once flowed past Sooty, Murshidabad, Nadia, and Calcutta, to the sea. He also stated "that Nuddea, from its name, once an island with salt "water round it, is now 130 miles from the sea, and the site of a city, up to "whose garden walls eighty years ago, the tidal wave, the bore, rolled; but "now it no longer approaches the town, and barely reaches Sooksagur, 24 miles "lower down the river."‡

From the evidence, apparently, given before the Committee of Enquiry in 1853 and 1854, Mr. Longridge, in 1861, deduced the following conclusions: "*First*, from Calcutta to Fulta House, the navigation, though tedious and trouble-"some, is not dangerous; and though subject to periodical changes, the depth "of water does not appear to have suffered any permanent diminution. "*Secondly*, from Fulta House to Kulpee, there appears to be evidence of some "permanent decrease in depth, though not yet to such an extent as to have "a serious effect on navigation. *Thirdly*, from Kulpee to the Sand Heads, the "evidence goes to show that there has been a decided and serious shoaling "of the water in the channels, and that a prolongation seawards of the tails "of the sands has taken place, to the extent of six miles within the last fifty "years." §

In 1864, Mr. J. Obbard, the River Surveyor, drew up a memorandum based upon an examination of all the records and charts to which he had access, in which he compared in detail the condition of the Húgli according to the earliest records up to 1836, the date of Lloyd's survey, and the alterations which had subsequently occurred. The general conclusions at which he arrived from his investigations were the following: "The channels from Saugor to sea are, "to say the least, in as good a condition as has ever been known. Between

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* "Report of the Committee appointed to enquire into the state of the River Hooghly," Calcutta, 1854, p. 16.

† Ibid. "Separate Report of Mr. H. Piddington," p. xix.

‡ "Report on the Rivers of Bengal," by Captain W. S. Sherwill, Calcutta, 1858.

§ "The Hooghly and the Mutla," by J. A. Longridge, Proceedings of the Inst. C.E., Vol. XXI, p.p. 11 to 12.

"Saugor and Mud Point it has changed considerably. The route of shipping "has been entirely diverted from the western to the eastern side of the river; "but it is doubtful whether navigation has, on the whole, been facilitated by "it or otherwise. Bedford's channel is more fluctuating than the old route was. "Between Mud Point and Kulpee there can be no question that the river has "become worse since 1836, and very much worse than it was in earlier times. "From Kulpee to Calcutta the river is neither better nor worse than it has "previously been." *

In his report of 1865, Mr. Leonard expressed his entire agreement with Mr. Obbard's opinion, and considered that it afforded "grounds for concluding that, if the river be considered as a whole, it has deteriorated since 1836, if not before that time." He further goes on to say that, "on examining the agencies which are at work in the river, it is difficult to come to any other conclusion than that it must deteriorate, however slowly. *First*, there is the enormous quantity of silt carried down every year, which must be deposited in or about the débouché, lengthening out the sand heads, and thus decreasing the scouring power of the stream. *Secondly*, there is the constant, though slow, widening of the lower section of the river, which tends to diminish the scouring power of the current, and also leaves more room for the channels to change from side to side." †

In October, 1893, Captain Petley wrote a note on the Húgli, comparing the condition of the river in 1893, between Kulpi and Saugor, with the survey made by Captain Charles Court in 1813-14, of which he was by chance enabled to obtain a copy; and he illustrated his note by two models of the bed of the estuary made from the surveys of the two dates, which are kept in the Board Room at the Port Commissioners' Office. After expressing doubts as to the value of conclusions based on *viva voce* evidence on the changes in the channels of the Húgli, such as that given before the Húgli Committee in 1853-54, and the great rarity of documentary evidence on the subject, he observed that "the bed of the river between Calcutta and Kulpee is, with the exception of the bars, fairly stationary. Between Kulpee and Saugor violent fluctuations occur in the depth of water, and considerable alterations in the courses of the channel have been the prominent phases in that section of the river; and below that to the Eastern Channel Lightship, the sands have been very gradually going seaward, and within the last ten years Lower Saugor Roads has very gradually filled up, affecting the depth of water in the channel in some places to the extent of 10 feet." ‡ The changes indicated in the estuary between 1814 and 1893 by a comparison of the models are recorded in the following extracts from the note: "A glance at the models will show that within that section of the river, the channel of to-day is an infinitely superior one to the channel of 1814, and the present course up or down the river is a straighter one." Taking into account the great increase in the number of buoys, the introduction of

* "Memorandum by J. Obbard, River Surveyor, upon the past and present condition of the River Hooghly." "Memorandum on the River Hooghly," by H. Leonard, Calcutta, 1864, p. 33.

† "Report on the River Hooghly," by Hugh Leonard, 1864, p. 13.

‡ The Commissioners for the Port of Calcutta, Proceedings, vol. XXVII, Appendix D., 13th October 1893. "Note on the Hooghly River between Kulpee and Saugor for the years 1814 and 1893."

tidal semaphore signals, and the employment of large steamers and powerful tugs, the conclusion is drawn "that the navigation of the Húgli is a far simpler matter to-day than it was in the early years of the century." The models show that the area of water represented has increased since 1814 from 180 to 188 square miles. "This disappearance of eight square miles of land represents 384,102,400 tons of earth, or taking the average disappearance of earth from this portion of the river yearly, it means that in 79 years 4,862,055 tons of earth have gone seaward each year. The right bank of the river shows both extensive cutting away and reclamation about Balari to Huldi river, but it is the left bank where the deterioration or loss of land has occurred. It has cut away right down the west side of Saugor Island from Mud Point to sea, and it is matter for reflection if this is part of the soil which goes down to assist the growth of the Sandheads. The river between Saugor and Kulpee is better now than it was 79 years ago; and above Kulpee beyond the seasonable changes, and at times the formations of sudden lumps, the river to Garden Reach is about the same as it always has been."

Remarks on Opinions as to Deterioration.—The conflicting nature of some of the above opinions as to the deterioration of the Húgli indicates how difficult it is to obtain a definite solution of such a complicated question. All the opinions agreed that the navigable channel from Calcutta to Kulpi, or at any rate to Fulta, had remained in a more or less stationary condition on the whole; but whilst five of the persons quoted above were of opinion that the estuary of the Húgli had deteriorated, Mr. Piddington, and Captain Petley with the advantage of more recent experience, considered that it had not; and Captain Petley further maintained that the navigable channel through the estuary in 1893 was far better than in 1814. It must be admitted that Captain Petley is right in placing little confidence in oral evidence, more especially when it is so conflicting as the evidence before the Húgli Committee. This Committee, however, evidently had access to the charts of 1813-14 and 1836, for the so-called sections of the river appended to their report were compiled from these charts; though they appear to have relied chiefly upon the evidence in drawing up their report. Mr. Obbard and Mr. Leonard, indeed, appear not to have had an opportunity of seeing the survey of 1813-14; but they were able to compare the later surveys of 1854 and 1864 with Lloyd's chart of 1836, as well as some charts of the 18th century of doubtful reliability.

COMPARISON OF CHARTS OF THE RIVER HÚGLI.

From an engineering point of view, old charts giving accurate representations of previous conditions of a river are so useful in indicating changes which have occurred, from which some idea of future changes may be deduced, that the loss of so many of the old surveys of the Húgli, made in the present century, is very unfortunate. It is very desirable that, in addition to preserving a complete set in duplicate of the excellent charts prepared every year under the superintendence of the Deputy Conservator, every effort should be made to obtain copies of the older surveys, reports, and other documents relating to the Húgli, not at present in the Commissioners' Office, so that as complete a record as possible of information about the Húgli may always be accessible there for reference.

Permanent Changes which might be found in the River Húgli.—Permanent changes in the Húgli may be the result of considerable modifications in the existing conditions, or of causes operating constantly or periodically, whose effects may be so gradual that they only become apparent from a comparison of the condition of the river after the lapse of some time. The change which, according to tradition, occurred about 1762 in the course of the Damuda, when it is believed to have burst its embankments, and deserting its old outlet into the Húgli at Noaserai, formed a new outlet further south, first at Ulabaria, and finally at its present position opposite Fulta,* is an instance of an abrupt change which deprived the Húgli, between Noaserai and Fulta, of a fresh-water discharge estimated at about 54,000 million cubic yards in a year, or not much less than one-half the fresh-water flow which has been estimated to flow at present, on the average, annually down that section of the river. A much smaller change of a similar nature was produced by the diversion of a large proportion of the flood waters of the Damuda into the Rupnarain by the Begooa breach in 1851, and the removal of thirty-five miles of embankment five years later, which only affected the five miles of river intervening between the mouths of the Damuda and the Rupnarain.

Changes due to the erosion of the shores of the estuary of the Húgli, such as have taken place along a considerable length of the coast-line of Saugor Island, are readily observed; but the erosion is in some cases followed by accretion, owing to alterations in the channels. Moreover, whilst the changes which appear likely to be permanent, such as the general increase in the area of the estuary may be sufficiently evident, the influence they may have upon the condition of the navigable channel is not so easily ascertained.

A gradual deterioration of the Húgli might be produced by the slow accumulation in its bed of some of the alluvium annually brought down from inland, which clearly was regarded as certain to occur by some of the persons who came to the conclusion that the river was deteriorating; or it might be caused by a progressive erosion of the concave banks of the river at sharp bends, increasing the windings of the channel and producing an advance of the sandbanks projecting from the convex banks. The accumulation of deposit might be expected to manifest itself first, either at the upper end of the Húgli near the tidal limit, or at its outlet. Permanent shoaling in the upper part of the Húgli would be occasioned by a reduction in the flow of the Ganges into the Nadia rivers, diminishing the scour available for clearing away the alluvium deposited during the abatement of the freshets, and brought up by the flood tide at springs in the dry season during the prevalence of the south-west monsoon. A silt-bearing river naturally deposits its burden of alluvium when its current is arrested on emerging into the open sea, unless the deposit is prevented by tidal action or a littoral current; and the Húgli would inevitably form a shoal at its outlet unless the tidal action is powerful enough to counteract this tendency.

Changes in the River Húgli above Calcutta.—With the exception of the cross sections of the Húgli at Dumardaha, taken in 1889 and 1896, previously

* This tradition is referred to by Capt. Sherwill, Mr. Longridge, and Mr. Leonard, and it is mentioned as a fact in Appendix Q of the Report of the Húgli Committee.

referred to, there are no surveys of the river available for comparison above Barrackpur ; for though the survey of the upper river made in 1885-86 extends to Shamnagar, the only other survey of this part of the river, made in 1875, only goes up as far as Barrackpur. Even the cross sections at Dumardaha are not strictly quite comparable, for the first was taken in the flood season, and the last at the close of the dry season ; so that probably the real increase in the cross section, since 1889, is greater than indicated.

In order to obtain some knowledge of the changes which may be occurring in this portion of the river, it would be necessary to have cross sections taken, at fixed points, between Nadia and Barrackpur, which should be taken again at the same period of the year, after the lapse of a few years, on precisely the same lines, and the two sets of sections compared. As, moreover, the condition of the upper part of the Húgli depends largely upon the supply derived from the Ganges by the Nadia rivers, it is desirable that the system of comparable cross sections should be extended to these rivers by the executive engineer ; for the discharges of these rivers must always be liable to considerable fluctuations, on account of the frequent changes in their inlets produced by the shifting of the channel of the Ganges. Several cross sections, and a longitudinal section of the Bhagirathi were, indeed, taken by one of the executive engineers of the Nadia rivers many years ago ; but this system, so judiciously inaugurated, was not followed up by his successors ; and the precise positions of the cross sections cannot now be determined. Records of this kind obtained at regular intervals, and also whenever some alteration in the general conditions might render them expedient, would be very valuable both in manifesting any changes in the Nadia rivers, and also in indicating the influences variations in their yearly discharges exercise on the Húgli.

The advantage of the introduction of a larger supply from the Ganges into the Húgli through the Nadia rivers, would depend upon whether the improvement of the upper river by the scour of the increased fresh-water discharge, resulting in an enlarged tidal capacity during the dry season, might be accompanied by a deterioration near the outlet by the deposit of some of the additional alluvium carried down, especially if a large proportion of this alluvium consisted of sand. Whilst, however, an increased discharge from the Ganges into the Húgli, though very advantageous to the upper part of the Húgli, might be attended by a greater tendency to the accumulation of a deposit of sand at the outlet, or in the approach channels, the diversion of the fresh-water flow of the Damuda from Noaserai to Fulta, and now practically, for the most part, into the Rupnarain, must have produced a considerable deterioration in the upper part of the Húgli by depriving it of nearly a third of its fresh-water discharge, without even the somewhat compensating advantage of a great reduction in the volume of alluvium carried down to the outlet. The observed curtailment of the tidal flow between Sooksagur and Nadia, mentioned by Captain Sherwill in his report, affords evidence of this deterioration, which would be the inevitable result of a large reduction in the fresh-water discharge ; for the descent of the freshets clears out the channel in the upper part of the Húgli, in proportion to the volume discharged ; and though some deposit occurs as the floods lower at the close

of the rainy season, the channel is to a great extent left open for the ascent of the flood tide during the dry season. A reduction, accordingly, in the fresh-water discharge produces a corresponding reduction in the section of the upper part of the river, and a proportionate decrease in the tidal scour throughout the dry season.

The oldest chart to which access has been obtained, showing the upper part of the Húgli above Calcutta as far as the town of Húgli, is supposed to have been drawn up towards the close of the seventeenth century ; and the absence of any indication of Calcutta upon it proves that it must date back to that period. This chart, though indicating some of the well-known features of the river below Calcutta, is very inaccurate as to the position and the lengths of the reaches between the bends, and the width of the river generally. The depths, however, which are given on the chart along the whole length of the navigable channel from Húgli to Diamond Sand, the southern limit of chart, which probably formed the main object of the chart, and could be obtained without the knowledge and instruments required for an accurate survey, may perhaps be regarded as somewhat comparable between themselves, though not with the depths of the present time in the absence of any datum. Now the soundings on this chart indicate depths along the river above the site of Calcutta, up to a little above the site of Chandernagore, approximately similar to the depths below down to Diamond Sand, which would not correctly represent the condition of the river at the present day, but which might well have been the case if the scouring power of the full discharge of the Damuda was in operation in the Húgli from Noaserai downwards.

For the sake of comparison, the surveys of the Húgli between Cossipur and Barrackpur, made in 1875 and 1885, have been reduced to the same scale ; and the low-water, and the 1-, 3-, and 5-fathom lines have been inserted in each case, the differences in depth being further plainly marked by different shades of blue, so that the general changes in the river between 1875 and 1885 are indicated at a glance, Plate 2, Figs. 1 and 2. Longitudinal sections have also been made from the two charts along the navigable channel, which have been placed together for the sake of comparison, Plate 2, Fig. 3. A comparison of the two surveys shows that the flats projecting from the convex bank at the bends have all altered somewhat in their low-water contours, some having extended, whilst others have been reduced. The main channel of the river in 1885, whilst maintaining the same general direction as in 1875, exhibits on the whole a distinct increase in depth, the only shoaling of importance having occurred near Cossipur, and a decided improvement being noticeable in the bend below Barrackpur. The decided improvement in depth, however, of the river in November-December 1885, as compared with November 1875, clearly indicated by the lengthening out of the 5-fathom contours on the plan and the general lowering of the bed of the river in the longitudinal section, may very probably have been due to the greater discharge of the freshets in 1885 than in 1875, for the heights of the Bhagirathi at Berhampur and of the Húgli at Noaserai, from July to October, were higher than the average in 1885, and lower than the average in 1875. Moreover in some places, such as the middle of Konnagar reach, the increase in

depth was accompanied by a reduction in the width of the 3-fathom channel, giving an undue importance to the deepening indicated on the longitudinal section. Changes of this kind in the channel of a river can be only fully indicated by comparative cross sections on identical lines, which it is impossible to obtain even roughly from the two surveys, as the earlier survey was made on quite a different system to that of 1885-86. On the whole, the condition of the portion of the Húgli between Cossipur and Barrackpur appears from the surveys to have been somewhat better in 1885 than in 1875 ; but an interval of ten years, and only two surveys, especially when preceded by flood seasons exhibiting a considerable difference in the rise of the river, do not afford an adequate period, or information of a sufficient comparative value, upon which to found an opinion as to the deterioration or improvement of this section of the river.

Changes in the Húgli must necessarily be slow in the absence of any marked change in the physical conditions, and must fluctuate from year to year according to the variations in the discharge of the freshets. The channel of the river is a sort of resultant of the various natural forces acting on it ; and there is no reason to anticipate its general deterioration, unless some distinct change occurs in the physical conditions to which it is subject, such as the transference of the discharge of the Damuda (draining a basin of about 7,300 square miles) from Noaserai to Fulta, or such an alteration as might be caused in the discharge of the Nadia rivers by a considerable diversion of the course of the Ganges eastwards.

Changes in the Ghusri Sand.—The very prominent sandbank projecting from the convex bank at the first bend of the river above Calcutta is the natural result of the enlargement of the Húgli to about double the width at this point which it has between its banks both above and below, caused no doubt by the gradual erosion of the concave left bank, on which the descending current from the straight reach above impinges directly, and by which it has to be diverted at a considerable angle towards Calcutta, Plate 2, Fig. 5. It is clearly of no recent growth, for it is plainly indicated on the chart of the seventeenth century as a large sandbank at that period, as well as in a chart of the eighteenth century. It has, however, experienced considerable variations, as indicated by the comparative contours of the low-water and 3-fathom lines made by Captain Petley from five surveys of the bank between 1857-58 and this year, Plate 2, Figs. 5 and 6, and Plate 4, Figs. 1 and 2. The sandbank appears to have extended out least far into the river at low-water in 1873-74, and to have been unconnected with the land ; whilst in 1857-58, a flood-tide channel had cut a considerable way into it at its lower end, and a detached bank had been formed off from it in 1882. The sandbank exhibited the largest dimensions in the surveys of May 1889 and 1896 ; but though the sandbank extended furthest into the river in 1889, a flood-tide channel was cutting into the bank close to the shore, which has since to a great extent disappeared. Whilst, however, the recent survey shows the bank further out than in 1873-74, it not only extends less into the river than in 1889, but also less than a narrow spit in 1857-58, and than the detached island in 1882.

Moreover, the 3-fathom line of 1896, in front of the sandbank, though approaching nearer to the opposite left bank of the river than in 1889, does not

come so near to the opposite shore as in 1873-4, or in one place as in 1882, and is all along further off than the 3-fathom line of 1857-8. Accordingly, although the Ghusri sandbank has a larger area at low tide than some years ago, the low-water channel has a greater minimum width now than in the previous surveys, except 1873-4, and the 3-fathom channel also, with the exception of 1889. The influence of the flood-tide on the tail of the sandbank is clearly marked in the survey of 1857-8; and its predominance after the short freshets of 1873 was manifested by the cutting back of the sandbank, and the formation of an inshore channel, indicated on the survey of 1873-4. In the absence of any erosion of the concave left bank of the river opposite the sandbank or any special alteration in the state of the river above, about which no information is available, the increased area of the sandbank emerging at low-water, shown on the last two surveys, taken in 1889 and 1896, after the short freshets of 1888 and the exceptionally low freshets of 1895, must be due to a diminution in the eroding action of the flood tide, resulting from a reduction in the strength of its flow or a change in its course produced by the works carried out in the river below. In spite, however, of the growth of the sandbank above low-water level, the navigable channel alongside it cannot be considered to have deteriorated, for both the low-water and 3-fathom channels are wider than in 1857-8. Nevertheless, the increased area of the sandbank, combined no doubt with a greater height towards the shore than formerly, must to some extent check the direct progress of the flood tide up the river.

CHANGES IN THE RIVER HÚGLI BETWEEN CALCUTTA AND HÚGLI POINT.

Indications of the early Charts.—Several of the principal shoals in this portion of the river are very roughly indicated in the chart of the seventeenth century already referred to, the Sibpur, College, Sankral, Munikhali, Koffri, Buj-Buj, Royapur, Brul, Fulta, and Húgli Point sands being more or less recognisable as well as a small patch of the James and Mary Sand near Mornington Point at the entrance to the Rupnarain. The charts also of the early and latter part of the eighteenth century show, in a very rough form, most of these sandbanks, the latter survey being the only one affording any indications of a trigonometrical survey and approximating to the proper width of the river. The chief points of interest, however, in these charts are that in the two earlier ones a river at Moundelgat is indicated flowing into the Húgli, at the site of the present outlet of the Damuda, and that only in the last does the name of this river appear; and also that in all three charts a rather prominent sandbank extends from the right bank of the Húgli above the mouth of the Rupnarain, occupying almost the site of the present less noticeable Shipgunj shoal.

A chart of the portion of the Húgli from Hangman's Point to the commencement of Buj-Buj Sand was made, to a large scale, in the dry seasons of 1780 and 1781, by Captain Mark Wood, R.E., which furnishes a valuable basis for comparison with the large scale charts, made in 1882-83 by Captain Petley, for indicating the changes in this unfortunately short section of the river in a period of 102 years, Plate 2, Fig. 7. The datum of the 1780-1 chart is low-water of

spring tides, whereas the datum of all recent charts is the lowest low-water ; and, accordingly, the datum has been lowered half a fathom on the reduced chart of 1780-1 to make the two levels approximately correspond. A comparison of the widths between the shore-lines in the two surveys indicates that, with the exception of the narrowest part at Munikhali Point, where there is an apparent reduction in width of 50 feet, there has been a widening throughout of the river between its banks, amounting to a maximum of 800 feet across the widest part of Sankral reach, and 700 feet at the narrowest part of the channel at Hangman's Point, and at a point in the Koffri reach. The widening is very slight at a narrow part of the upper portion of Buj-Buj reach, but increases again to 150 feet at the head of Buj-Buj Sand. The Munikhali Sand, however, which extended 1,450 feet from the right bank of the river in 1781, projected only 900 feet from the bank at the lowest low-water in 1883 ; but, on the other hand, the Sankral Sand which appeared merely as a bank in mid-river, about 1,800 feet long, though only separated from the left bank of the river by shoal water with a maximum depth of 9 feet at low tide, had developed into a sandbank extending out 3,600 feet from the shore, and stretching from Hangman's Point nearly down to opposite Munikhali Point, Plate 2, Fig. 5. Moreover, Koffri Sand, which in 1781 consisted of two banks along the shore of moderate dimensions, with a maximum projection of about 550 feet, had grown into one continuous bank in 1883, extending considerably beyond the extreme limits of the former banks, and jutting out about 1,050 feet from the shore. Owing, however, to the widening of the river, the low-water channel has not become narrower in front of either Sankral or Koffri sands, if allowance is made for the difference in datum of the two surveys ; and it is considerably wider alongside Munikhali Sand. With regard to the depths in the navigable channel, there appears to have been remarkably little alteration in the century under consideration. The depths seem to be considerably greater in the survey of 1882-83 above Hangman's Point than in that of 1780-1, somewhat shallower in the main channel along the upper part of Sankral Sand, and deeper again along the lower part down to Munikhali Point, decidedly less deep close to the left bank in the concave bend opposite Munikhali Sand, and then deeper in some places and shallower in others down to the head of Buj-Buj Sand, opposite to which the soundings on the chart of 1882-3 are less than on the old chart which terminates at this point. Accordingly, the main changes in this portion of the Húgli after the lapse of a century, are an increase in width generally between the banks, and especially at certain bends, followed by an extension of the adjacent sandbanks. The apparently anomalous reduction in Munikhali Sand may be traced to the maintenance of the course of the descending current near the right bank round Munikhali Point, owing to the remarkable extension of Sankral Sand downstream, which also accounts for the absence of any enlargement of the river in front of Munikhali Point, and for the shoaling of the channel close along the left bank in the concave bend below.

Changes indicated by the Chart of 1813-14.—The survey of the Húgli by Captain C. Court, Marine Surveyor, in 1813-14, appears to be the earliest chart of the river, as a whole, upon which any reliance can be placed for purposes of comparison. Unfortunately, however, this chart exhibits mainly the depths in the navigable channel, and gives comparatively few soundings over most of the

shoals ; and it does not indicate the outlines of the sandbanks at low-water. Accordingly, the chief value of the chart for an investigation into the changes of the river consists in the general outline of the banks of the river at that period, and the position and depths of the navigable channel.

Comparing the widths between the banks of the Húgli in 1813-14 with the survey of 1888 from Sankral, where the earlier survey partially commences, down to Húgli Point, the chart of 1888 indicates a moderate increase in width off Hangman's Point, at Koffri Point and in the reach below, and at Buj-Buj Point. The river has apparently been narrowed at Ulabaria, and along a length of about 2,000 yards in the bend below Moyapur Magazine, but has decidedly widened along the upper part of the Moyapur reach ; and there has been a small increase in width across Brul Sand and at Dhaja Point. The James and Mary reach has become wider along most of its length, the increase in width having been considerable from a little below Fulta Point to the Nila Obelisk, with a maximum of about 1,000 feet, Plate 2, Fig. 8 ; whilst the river has become somewhat broader between Húgli Point and Gewankhali, owing to the erosion of the point which formerly projected at the south side of the outlet of the Rupnarain.

The navigable channel of the Húgli between Koffri Sand and Húgli Point followed a course in 1813-14 very similar to its present one, Plate 2, Fig. 5 ; and the depths in the main channel at that period are shown on the longitudinal section compiled from the chart, Plate 3, Fig. 13. Allowing for the variations which inevitably occur in longitudinal sections, where the soundings may miss elevations and depressions in the bed recorded by previous soundings, and where a small modification in the line selected may make a difference of some feet in the section, the sections of 1813-14 and 1888 correspond fairly well on the average, except that at the Moyapur and James and Mary shoals the available depths were 6 feet and 4 feet less respectively in 1888 than in 1813-14.

Comparison of the Charts of 1836 and 1888.—The earliest, and in fact the only chart at all suitable for a general comparison of the Húgli between Calcutta and Húgli Point, is Captain R. Lloyd's chart of 1836 ; for the next chart of the upper part of the river was merely compiled from the river surveys of 1867 to 1882, and therefore does not indicate the state of the river at any particular year between these dates ; whilst the first of Captain Petley's systematic charts consists of the large-scale sheets of the survey of 1882-3, which was too close to the last published survey of the whole river in 1888 to afford a favourable opportunity for noting any permanent changes in the river. Accordingly, the chart of 1836, down to Luff Point, has been reproduced on Plate 2, Fig. 4, to the same scale as the original, with the 5-fathom, and in some places the 10-fathom lines added; and in order to render the differences in depth discernible at a glance, the spaces between the fathom lines have been shaded in blue in gradations, increasing with the depth, from low-water and the 1-fathom line, up to the 10-fathom line and upwards—a system which has been followed in all the other charts illustrating this Report. The chart of 1888 has been reproduced in like manner, slightly enlarged to correspond in scale with the chart of 1836 ; and it has been placed immediately below the

other on Plate 2, in the hope that as these two charts, Plate 2, Figs. 4 and 5, were the only ones available previously to September last for comparison of this part of the river, they might afford an indication of the general changes of the Húgli, betwen Calcutta and Luff Point, in an interval of fifty-two years. These charts do, indeed, serve to show the changes in the width between the banks of the river during this period, and the general stability of the navigable channel; but there are strong grounds for believing that these charts, though faithful representations of the original documents, do not present a fair comparison of the extent of the sandbanks above low-water, and the depths in the channel at the two dates, owing to certain indications in these respects discovered in the chart of 1836, pointing to a considerable difference in the datum to which the soundings were reduced in the two charts, or a peculiar condition of the river in 1836.

Since 1836, a comparison of the two charts shows that there has been a decrease in width between the banks at Munikhali Point, below Moyapur Magazine, and at Ulabaria; and a considerable increase in width across Sankral Sand, and some enlargement along Royapur Sand, at places in the James and Mary reach, and from Húgli Point across to Gewankhali. It is evident that, with the exception of the fluctuations at Moyapur and the James and Mary shoals, the navigable channel remains very stable in position along the course naturally followed by the descending current.

As regards the area of the sandbanks dry at low-water and the depth along the navigable channel, a very cursory inspection of the two charts, Plate 2, Figs. 4 and 5, would appear to demonstrate a deterioration in the Húgli; for with the single exception of Achipur Sand, opposite Ulabaria, where the channel has been narrowed, all the sandbanks existing in 1836 have been extended, and fresh ones have since appeared; whilst the 5-fathom contour which extended with only three breaks (one of which was at Moyapur) from Calcutta to Ninan in 1836, exhibited several breaks in 1888. A careful investigation, however, with the view of testing the accuracy of the results obtained by this process of comparison, showed that, whatever may be the accuracy of the chart of 1836, it does not fairly represent a normal condition of the river. Mr. Obbard, indeed, stated in his memorandum on the Húgli in 1864, that he considered that Lloyd's soundings required a reduction of 18 inches to correspond with the lowest low-water datum, which had at that time been adopted by Mr. Bedford, the River Surveyor; but this would only produce a comparatively small modification in the chart. A comparison, however, of the survey of 1780-1 with the corresponding portion of Lloyd's survey, the datum of each of which is stated on the charts to be low-water of spring tides during the dry season, indicates some remarkable differences between the two, Plate 2, Figs. 4 and 7.* The survey of 1780-1, like the survey of 1888, indicates a foreshore of sand round Hangman's Point at low-water, which does not appear in the survey of 1836. The survey of 1836 does, indeed, show two insular sand banks on the site of Sankral Sand, where only one existed in 1780-1; but this growth seems remarkably small considering

* The datum of the reduced chart of 1780-1 has been lowered half a fathom to render it fairly comparable with the recent charts; but the comparison of this chart with that of 1836 is based on the indications of the copy of the actual survey of 1780-1.

that the river had already increased 300 feet in width there since 1780-1, out of a total increase of 800 feet up to 1883, and in view of the great size of the present Sankral sand. Moreover, the comparatively small detached patch of sand off Munikhali Point, shown on the survey of 1836, is hardly likely to represent accurately the state of Munikhali Sand at that date, at low-water of spring tides, considering the extensive sandbank connected with the shore which existed in 1781, its present extent, and its protected position from scour by the freshets. Still more improbable is it that the two Koffri sandbanks, which stretched out 550 and 400 feet from the shore at low-water in 1781, and had a total length of 4,250 feet, and which have since grown into the present long sandbank, should have entirely disappeared in 1836, though most of the widening at that part since 1781 had already taken place. Buj-Buj Sand also, which is only partly shown on the chart of 1780-1, at a distance of 2,900 feet below the point, extended out 1,300 feet from the shore at low-water in 1781, and 1,100 feet in 1883 at the same place ; whereas, on the survey of 1836 the width of the sandbank there is only 500 feet. These anomalies in the chart of 1836, lead irresistibly to the conclusion that the datum of the soundings for the upper portion of the chart of 1836 must have been two or three feet higher than that of the chart of 1780-1, and therefore still more above the lowest low-water datum of the chart of 1888. The unusual lowness of the bed of the river in the navigable channel in the chart of 1836, owing to the height of the datum, combined possibly with a favourable condition of the river, such as existed in 1883, is very noticeable on the longitudinal section, Plate 3, Fig. 13, on which the section of 1836 is most remarkably lower, on the average, throughout than the section of 1813-14, from the commencement of the latter survey in detail at Pir Serang down to Kantabaria, the only notable exception being at the Moyapur shoal, where, however, the minimum depth in the survey of 1836 was 15 feet. Moreover, the survey of 1836 indicates a greater depth over the bar at the lower end of the Eastern Gut than any of the other principal surveys, amounting to a minimum of 19½ feet ; whilst the minimum depth given across the bar of the Western Gut in the same survey is 13½ feet.

It is evident, therefore, that the survey of 1836 cannot be regarded as suitable for exact comparison with other surveys of the Húgli in respect of depths ; and even if the correctness of its datum did not appear doubtful, the surveys of 1780-1 and 1813-14 amply prove that the good condition of the river exhibited on the survey of 1836 had not always existed before that period.

Comparison of the Charts of 1867-82 and 1888.—The chart compiled from the river surveys between 1867 and 1882 appears to have been the only complete chart of the river, between Calcutta and the estuary, published between Lloyd's chart of 1836 and Captain Petley's large-scale survey of 1882-3. In this chart, a portion of the Sibpur Sand formed an island at low-water, just below Howrah, near the right bank, to which it became united by 1888, though stretching less far into the river at some parts at its upper end. No Shalimar, or College Sand, emerging at low-water, appears on the earlier survey ; whereas in 1888, this Sand extended from Bharpara Khal more than a mile down the river. This sandbank is evidently the result of a large reclamation carried out along

the foreshore of the right bank of the river in front of Sibpur, and opposite the Docks, between the periods of the two surveys, which at the lower end abruptly narrows the river, from a previous width of about 1,870 feet to a width of 1,560 feet between the banks ; whereas widths of 2,700, and 2,450 feet are found a short distance above and below, respectively. Such a reclamation in a river like the Húgli, combined with a sudden restriction in width where the river was already narrower than above and below, is prejudicial to the maintenance of the navigable condition of the river.

Between the surveys of 1867-82 and 1888, the river widened somewhat at Sankral Sand ; and this sandbank, though reduced in extent round Hangman's Point, extended considerably down-stream ; whilst Munikhali Sand underwent very little change beyond being cut into at its lower end by the flood tide. Koffri Sand had increased considerably in length in 1888, but had been diminished in width ; whilst the tail of Buj-Buj Sand had been considerably shortened, as compared with the earlier survey. Achipur Sand appears to have been much reduced in extent between the dates of the two surveys ; and Moyapur reach, though very similar in width at both periods, exhibited a tendency to continue becoming narrower below the magazine. This narrowing of the river in a bend has probably been due to the accretion produced by the spurs put in with this object by Mr. Leonard between 1865 and 1870.* In the same period Royapur Sand crept upwards round Hiragunj Point, but was largely reduced in extent below the point. The head of Brul Sand had been cut away to some extent nearly down to opposite Brul Tower, which was accompanied by an increase in the width of the sandbank for some distance below, without, however, increasing the maximum projection of the sandbank beyond the extent indicated on the earlier survey ; whilst the tail of the sand was reduced. A considerable change took place at Fulta Sand within this period ; for whereas the survey of 1867-82 shows a large sandbank emerging in mid-river at low-water, with a channel between it and Dhaja Flat, having depths of 8 to 15 feet at the lowest tide, though with a bar below separating it from the main channel, with a depth of only 6 feet over it. This channel had practically disappeared in 1888 ; and a shoal, with a maximum depth of 7 feet, extended out from Dhaja Flat to the main channel close along the right bank ; whilst the area of sandbank dry at low-water had been greatly reduced.

The depths along the main channel indicated on the survey of 1867-82, are given on the longitudinal section in Plate 3, Fig. 13, between Calcutta and Kulpi, in which it will be noticed that the section of 1867-82 is intermediate between the sections of 1813-14 and 1836, though exhibiting a nearer approximation in most places to the earlier survey than to that of 1836. The longitudinal sections of the river in 1867-82 and in 1888, between Calcutta and Húgli Point, exhibit considerable differences in depth at various points, like all the other longitudinal sections ; but, on the whole, the longitudinal section from the survey of 1867-82 manifests a better general average depth than the section of 1888, Plate 3, Figs. 13 and 14 ; whilst the average depth

* "Report on the Works undertaken for the improvement of the Moyapore Shoal," by George Robertson, Calcutta, 1872.

indicated by the longitudinal section of 1883 is decidedly greater than that of 1867-82.

Comparison of the Surveys of the River Húgli of 1882-3 and 1896.—A large-scale survey of the Húgli between Calcutta and Luff Point, made this year,* of which a copy was received in September, enables an accurate comparison to be made between the condition of the river, between Calcutta and Luff Point, in 1883 and at the present time; for the large-scale surveys of both 1882-3 and 1896 were made under the superintendence of Captain Petley, and the soundings on them have been reduced to the lowest low-water, constituting the zeros of the tide-gauges along the river, the levels of which have been ascertained with reference to Kidderpur Old Dock Sill. The period, indeed, of thirteen years between the two surveys is comparatively short; but the large scales to which the surveys have been plotted enable somewhat small changes to be readily noted. In order to facilitate the comparison of the state of the Húgli at the two periods, the two surveys, composed of several sheets, have been reduced to a uniform scale, one-fourth the scale of the recent survey ; and the several parts have been connected so as to form a miniature plan of each survey, showing the river in two halves to save space, from Calcutta to Achipur Point, and from Achipur Point to Luff Point; and the two reduced surveys of the river have been placed side by side on Plate 4. Comparative cross sections have also been made, from the soundings across the river recorded on the two surveys, at twenty-six places not comprised in the cross sections on Plates 3, 6, and 8, indicating the differences in the bed of the river at the two dates at the points selected, from below Shalimar Sand to Fulta Point; and longitudinal sections of the river at the two periods have been prepared from the soundings given along the centre of the navigable channel, Plate 5.

Between the surveys of 1882-3 and 1896, the width of the river from bank to bank appears to have increased about 40 feet in the bend at Hangman's Point, 110 feet at the widest part across Sankral Sand, 50 feet opposite Munikhali Point, 150 feet across Munikhali Sand, 70 feet across the widest part of Koffri reach, 110 feet at Buj-Buj Point, 130 feet across Buj-Buj Sand at the widest part, 60 feet in Moyapur reach near Chapar Khal, 200 feet in the widest part of the bend below Hiragunj Point, and the same opposite Brul Point, 230 feet across Mitakundo Flat, 380 feet across Fulta Sand, 260 feet opposite Fulta Point, 200 feet opposite Shipgunj Point, and about 300 feet opposite Hope's Obelisk and between Húgli Point and the Gewankhali shoreline. On the other hand, there appears to have been a reduction in width of about 90 feet in the bend below Moyapur Magazine since 1883, and of about 80 feet opposite Pukuria Point ; but with these exceptions, the river between Calcutta and Húgli Point indicates no tendency to become narrower by accretion. The sandbanks rising above low-water, along the convex banks at the bends, exhibit considerable modifications in shape and extent, in the recent survey, from the outlines they possessed in 1883, Plate 4. These sandbanks have all

* The survey of the James and Mary reach was made in December 1895, but the rest of the river between Calcutta and Kulpi was surveyed in 1896 ; and therefore the new survey will be referred to as the survey of 1896.

extended up-stream; whilst in most cases this growth at the head has been more than counterbalanced by a considerable erosion at the tail by the flood tide. Thus the Shalimar Sand, though prevented by the projecting reclamation from creeping up-stream, has extended 120 feet further out into the river opposite the College, thereby making the narrowest part of the low-water channel alongside it about 110 feet narrower than in 1883; whereas lower down it has been reduced 650 feet in width at the part where it formerly projected furthest out, and its tail has been cut back 1,720 feet. Sankral Sand, also, has extended a good deal up-stream round Hangman's Point; whilst a great change has taken place above low-water in the main bank below the point, reducing its maximum width at low-water by about 1,130 feet, or nearly one-third. Though the tail of Munikhali Sand has been somewhat eroded by the flood tide, the projection of the sandbank into the river towards its head has been nearly doubled, this large extension being probably partly due to the alteration in the direction of the ebb current by the great modification of the tail of Sankral Sand. Koffri Sand has been slightly diminished in maximum projection, and its extension down-stream has been reduced by 300 feet; whilst Buj-Buj Sand, not only projects 450 feet less into the river, but its tail has been reduced 3,700 feet. Achipur Sand has crept a long way round the point up-stream; whilst the flood tide has attacked its tail. Royapur Sand has extended up-stream, its width has been doubled near Hiragunj Point, and its tail has been cut into by the flood tide; whilst the small detached sandbanks in front of it, which existed in 1883, have disappeared. Brul Sand has grown bodily up-stream, but its width has been reduced considerably by erosion below; and the long tail it possessed in 1883, is now only represented by a detached bank, 2,700 feet higher up the river than its former termination. Mitakundo Flat has grown out 300 feet into the river at its widest part; and a sandbank stretches right across the mouth of the Damuda at low tide in the dry season, where a narrow low-water channel existed close alongside the right bank of the river in 1883; whilst the Damuda Flat, along the right bank of the Húgli just below the outlet of the Damuda, has, on the contrary, been greatly reduced. The portion of Fulta Sand, which becomes dry at low-water, has increased in area, and has shifted about 3,000 feet up-stream; and the flood tide has cut into the lower portion of the shoal at the 1-fathom depth, and has practically obliterated the minor channel between Fulta Sand and the right bank of the Húgli, which was still in existence in 1883, but of which the only remaining trace is a narrow hollow extending into the sandbank across the mouth of the Damuda.

The 3-fathom channel in Hastings reach has receded from the left bank between Fort William and Tolly's Nala since 1883, and has become 200 to 300 feet narrower; whilst the interval between the 5-fathom contours at this part has increased 700 feet, and at the lower end of Garden Reach, 450 feet, Plate 4. At the lower end of Jarmaker reach above Pir Serang, there is a gap of 800 feet in the 5-fathom channel where it was continuous in 1883; and this channel has become narrower above Achipur Point. At Moyapur crossing, the gap that has to be traversed between the 5-fathom channels above and below, is about 1,350 feet longer in the 1896 survey than in that of 1883; and in the recent survey, there is an interval of about 1,450 feet of shoaler depth between the

3-fathom channels along the crossing track, where in the 1882-3 survey the 3-fathom channel was unbroken. At Royapur crossing, the great retrogression of the upper 5-fathom contour in the survey of 1896, as compared with the 1882-3 survey, has increased the navigable distance between the 5-fathom channels above and below by about 5,000 feet; whilst opposite Mitakundo Flat, the 3-fathom channel has become narrower, but more uniform in width. The deep hollows of ten fathoms and upwards have decreased in area in the bend off Munikhali Point, opposite Koffri Sand, and alongside Royapur and Brul Sands. The only compensations for the above reductions in depth are that opposite Fulta Sand, the 3-fathom channel has become wider, and the interval between the 5-fathom channels has been reduced 100 feet in length; and depths of 10 fathoms and upwards have increased in extent opposite Hangman's Point, and have appeared in three spots off Achipur Point, where no portion of the channel had a depth of 10 fathoms in 1883.

The above comparison of the lines of soundings given on the surveys of 1882-3 and 1896, Plate 4, seems at first sight to indicate a marked deterioration of the Húgli, between Calcutta and Fisherman's Point, since 1883. It has, however, been already noticed, from a comparison of the longitudinal sections, that whilst the survey of 1867-82 indicates a better average depth in the navigable channel than the survey of 1813-14, it exhibits a condition of the river distinctly inferior in this respect to that shown in the survey of 1882-3, Plate 3, Figs. 13 and 14. This points to the conclusion that the navigable channel of the Húgli is subject to fluctuations in depth from time to time, and that it was in a somewhat specially good condition, between Calcutta and Húgli Point, in 1883. The more favourable condition of the river, as regards its general navigable depth, in 1883 than in 1896, is readily accounted for by the difference in the height of the freshets preceding the two surveys; for whereas the freshets of 1882 were somewhat above the general average in height and duration, the freshets of 1895 were exceptionally low in their rise and short in duration. The deficiency in the freshets of 1895 has given a preponderating influence to the flood tide, resulting in the erosion of the tails of the sandbanks already described, and exhibited on Plate 4, and the conveyance of the sand further up the river, which has produced the extension at the heads of the sandbanks, and a shoaling in parts of the channel above them, as indicated by a comparison of the lines of soundings and longitudinal sections of 1883 and 1896, Plate 4, and Plate 5, Fig. 27.

Comparison of Sections of the River Húgli near Calcutta.—Except within the Port, from Howrah Bridge to a little below Kidderpur, where thirteen cross sections were taken in 1873-4, and retaken on the same lines in three subsequent years, no cross sections appear to have been made of the Húgli between Calcutta and the estuary previously to those taken early this year at my request, for comparison with which the only available information consists of the soundings given on the large-scale survey of 1882-3. Two of the cross sections of the river within the Port have been drawn to a small scale on Plate 3; and the other ten cross sections on the same plan furnish a comparison of the cross sections of the Húgli taken last February, with the depths given on the survey of 1882-3

along approximately the same lines, the positions of which are indicated on the general plan of the river, Plate 1, Fig. 3.

The thirteen cross sections taken within the Port in 1878-9, show that a considerable amount of accretion had taken place in this portion of the river since the sections were first taken in 1873-4, mainly on the Howrah side of the river, accompanied by a decrease in depth, in all but one of the sections, in the main channel, which for the most part keeps along the Calcutta side of the river. These changes, involving evidently an extensive alteration of the Sibpur shoal, cannot be attributed to differences in the freshets preceding the two sets of sections, for according to the readings of the Berhampur gauge (the only data available for 1873), the freshets of 1873 were somewhat less than those of 1878; but it is very probable that the changes were produced by the preponderating flood tides in 1877-8 after the exceptionally low freshets of 1877. The extensive reclamations carried out along the Sibpur foreshore in 1881-3, and the smaller encroachments on the opposite foreshore between Fort William and Kidderpur, limit the comparison of the sections of 1878-79 with the next set of sections, taken in 1888-9, to the portions not comprised within the reclamations. The narrowing of the river between Howrah Station and Shalimar House, aided by the somewhat higher freshets in 1888 than in 1878, produced changes in the river bed, in which the erosion was considerably greater than the accretion, the erosion having mainly occurred along the Sibpur foreshore in the upper wider part of the reach, and in the deep channel close to the left bank along the narrow part of the river in front of Kidderpur. The erosion, however, on the Sibpur foreshore was accompanied in some parts by a reduction in the maximum depth; whilst the increased section in the narrowed river did not nearly compensate for the abstraction by the reclamations; and in fact the average section of this part of the river in 1888-9 was approximately similar to that of 1873-4, exclusive of the portion now shut off from the river. The sections taken this year show that after the exceptionally low freshets of 1895, the bed of this portion of the river had decreased a good deal in section; and the maximum depth had been reduced as compared with 1888-9, except opposite Telkul Ghat, and in front of the projection at Fort William, where apparently some materials had been recently deposited at the time of the previous sections in 1888-9, possibly in connection with the building out of the base of the Gwalior Monument. The decrease in depth was most marked in the deep navigable channel along the Kidderpur shore in the bend, which was accompanied by some erosion along the Shalimar foreshore. Except in the narrow bend, and opposite Telkul Ghat and the projection at Fort William, the sectional area of the river is less now than the corresponding portion was in 1878-9, notwithstanding the reduction in width effected by the reclamations.

As a sandbank seems to have existed for a long period in the recess of the wide part of the river along the Sibpur foreshore, a reclamation might safely have been carried out for trade purposes within this recess, especially if the resulting loss of tidal capacity by this regulation of the channel had been, as far as

practicable, compensated for by dredging a deeper channel to facilitate the progress of the flood tide into the upper reaches. The abrupt narrowing, however, of the river in a narrow bend, though naturally producing some increase in depth along the concave bank, has not been accompanied by any general permanent enlargement of the narrow channel, so that, not only has the tidal capacity of this part of the river been reduced by the reclamations, but the progress of the flood tide has also been somewhat checked. Moreover, owing to the configuration of the banks of the river above and below the Kidderpur bend, the main current of the freshets and ebb tide keeps close along the Kidderpur shore in the bend; whilst the flood tide tends to flow along the Shalimar shore. Accordingly, when strong freshets prevail, the projecting reclamation at Shalimar Point favours the deposit of sand, brought down by the freshets, in the slack water under its shelter, which has resulted in the extension of Shalimar shoal and its raising above low-water in the path of the flood-tide current. Consequently, in seasons when the freshets are powerful, Shalimar Sand is extended and raised considerably more than before the reclamation was carried out, and the main channel is deepened; whilst after a season of low freshets, Shalimar Sand is more effectually eroded by the predominating flood tide which carries the sand into the main channel and into the wide reach above, Plate 4. Therefore in addition to the loss of tidal capacity, and a checking of the flood tide by the narrowed section, the projecting reclamation has intensified the changes produced in the river at this part by seasons of high and low freshets; whereas it should be the object of all works on the river to reduce these inevitable fluctuations as much as possible, and to facilitate the progress of the flood tide. When the present period of low freshets is succeeded by high freshets, the channel will doubtless deepen again and Shalimar Sand extend; but the restriction of the channel renders the state of the river more subject to variations in its vicinity, and more dependent upon the strength of the freshets.

Cross Sections of the River Húgli between Garden Reach and Diamond Harbour.—In addition to the ten comparative cross sections of the Húgli, at selected points between the Botanical Gardens and Buffalo Point, on Plate 3, Figs. 3 to 12, contrasting the state of the channel in February last with that indicated by the survey of 1882-3, cross sections have been prepared from the soundings given on the large-scale surveys of 1882-3 and 1896, at twenty-six other points indicated on Plate 4, mostly chosen where the recent survey showed that some change had occurred, between Shalimar Sand and Fulta Point, Plate 5, Figs. 1 to 26. Of the thirty-six cross sections, twenty-two show a greater amount of accretion than erosion in 1896 as compared with 1882-3, and ten a predominance of erosion; whilst in twenty the maximum depth shows a decrease in 1896, and in twelve an increase. This bears out the indications given by the surveys, Plate 4, that the general condition of the river between Calcutta and Húgli Point was less good in the early part of 1896 than in the dry season of 1882-3, notwithstanding the reduction in area of some of the large sandbanks emerging above low-water. In fact, the erosion of the tail of a sandbank by the flood tide is generally accompanied by shoaling in the adjacent main channel; whilst the advance of the head of a

sandbank upstream, in the absence of strong freshets, leads ordinarily to the deepening of the adjoining channel, and some shoaling in the reach above. This is well illustrated by the cross sections between Sankral Sand and Achipur. The cross sections which exhibit the greatest changes are those in the bends at Sankral, Munikhali, Achipur, Brul, Fulta, Húgli Point, and Buffalo Point; and the sections across the straight reaches between the bends are least subject to alteration. The freshets and ebb tide, indeed, form and maintain the navigable channel round the concave bends; and so long as strong freshets come down during the rainy season, the channel is sufficiently deepened, and the sand adequately raised and their tails extended, to prevent the flood tide in the dry season from producing a serious deterioration by cutting deeply into the projecting sandbanks, which not only diverts its scouring action from the main channel, but also occasions a deposit of the eroded sand in the channel alongside and above. When, however, the freshets are very deficient both in strength and duration, as in 1895, the channel in the concave bends is less deep, and the tails of the sandbanks are less extended at the close of the rainy season; and consequently the flood tide establishes its ascendancy sooner and with greater effect, and though lowering the sandbanks, pushes them somewhat upwards, and reduces the depth in the main channel, except where the protruded head of the sandbank contracts the channel. The flood tide by cutting into and lowering the sandbanks projecting from the convex banks, may perhaps, by obtaining a straighter course, accelerate somewhat its progress up the river, but possibly not materially as compared with its flow up a deepened channel after high freshets; and in any case, the resulting ebb tide in the dry season is not able to remove all the deposit brought into the main channel by the flood tide.

Longitudinal Sections of the River Húgli.—The longitudinal sections of the Húgli, given on Plate 3, Figs. 13 and 14, have been obtained from the soundings in the navigable channel given on the principal charts which have been made between Court's survey of 1813-14 and the latest complete chart of the river from Calcutta to the sea, of 1888, to which has been added a section made from soundings taken along the navigable channel in February 1896. These longitudinal sections afford an indication of the general prevailing navigable depth in the main channel at the date of each survey, and of the situation and changes in height of the various bars along the river. The lines along which the sections have been taken necessarily differ in position, according to the changes which occur in the position of the deepest channel, even to some extent above the estuary, and far more in the wide estuary; and therefore the differences in level of the several longitudinal sections, unlike the cross sections, do not necessarily indicate a corresponding amount of erosion or accretion; for the alterations in the river above the estuary may be partly owing to modifications in the course of the channel, and in the estuary on account of quite a different line of channel being adopted. The only longitudinal sections to which such a comparison could be at all fairly applied are those taken from the large-scale surveys of 1882-3 and 1896, Plate 5, Fig. 27; and it has not been possible to take even these sections along absolutely identical lines, owing to modifications in position of the central line of the deep channel (along which these two sections have been approximately

taken) between the dates of the two surveys. In addition to differences in the longitudinal sections which may arise from uncertainties in the choice of the line to be followed, some of the discrepancies may be due, in the sections from the earlier charts, to differences in the datum to which the soundings are referred, and in the sections from the small-scale charts, such as 1867-82 and 1888, to the comparatively small number of soundings given, which is the probable cause of some rather remarkable divergencies of the longitudinal section of 1888 from that of 1882-3. The difficulties in the way of making strictly comparable longitudinal sections of a river render them less reliable for indicating changes in a river than cross sections taken along absolutely identical lines; and, moreover, the cross sections show that small changes in the maximum depth may be accompanied by large alterations in the channel. Nevertheless, longitudinal sections form very useful supplements to cross sections, in indicating changes in the navigable depth, and in the position and height of the shoals.

The most noticeable features in the longitudinal sections are the considerable permanent irregularities and periodical fluctuations in depth throughout the navigable channel above the estuary, and the comparatively uniform and stable depth of the channel through the estuary, ranging for the most part between 3 and 5 fathoms below the lowest low-water, except across the bars, and generally only attaining 7 fathoms in the deep hollow of Saugor Roads, produced by the scour of the flood tide round the south-west corner of Saugor Island in entering the estuary from the south-east. The permanent irregularities in depth in the river portion are due to the scour of the descending current round the concave banks in the bends, and the shoals which are invariably found where the main channel crosses over from one bend to the next bend below along the opposite bank, producing alternate deep hollows and bars clearly indicated on the charts and longitudinal sections, Plates 2 to 5. Of the bars at the ten crossings between Calcutta and Kantabaria, as well as the bar above Kidderpur, resulting apparently from the diversion of the descending current by Fort Point, only the bars at Moyapur and the James and Mary reach rise above the 3-fathom depth at the lowest low-water; though the Royapur bar was only two feet below it when surveyed in May 1896. The greater height of these two bars is due to the more unfavourable configuration of the banks of the river in their vicinity, and the greater width of the channel at these places than at the other crossings, which produce a greater divergence between the courses of the flood and ebb tides at these crossings. The defects, indeed, of configuration and large width are so great in the James and Mary reach that the flood and ebb tides run along opposite banks in this wide reach, leaving an extensive shoal between their channels; and the descending current emerges from the Eastern Gut in a direction at right-angles to the course of the flood tide below Húgli Point, Plate 7. At Moyapur, the straightness of the reach below the Ulabaria bend, and a considerable enlargement in the width of the river between Achipur Point and the crossing near Moyapur Magazine, prevent the ebb tide from being directed over towards the flood tide channel running close along the opposite bank from the concave bend below. Accordingly, the channels of the ebb and flood tides keep close to the

opposite banks of the river along the Moyapur reach ; and the navigable channel connecting them is shifting in position and variable in depth, according to the strength of the freshets or the predominance of the flood tide, Plate 6.

The longitudinal sections of 1882-3 and 1896 indicate clearly the action of the flood tide after very low freshets, in pushing the bars somewhat further up the river and raising them higher than after a season of high freshets, Plate 5, Fig. 27. The alternate action of the freshets and flood tide on the bars and banks in the river occurs necessarily every year according to the seasons ; but the condition of the bars and the shape of the banks and shoals, at any particular period of the dry season, depend largely upon the strength and continuance of the freshets during the preceding rainy season. The freshets constitute the chief physical influence affecting the condition of the river, which fluctuates considerably from year to year ; and in order to obtain the most comparable yearly reports on the condition of the river, and the changes it has experienced, the year should begin with the commencement of the freshets in July ; and one of the earliest statements in each year's report should relate to the freshets, not only as the first important occurrence in point of time in a year beginning with July, but also as the most variable, and therefore the most likely feature to introduce changes in the river. The freshets also in proportion to their strength scour out the non-tidal feeders of the Húgli, and thus facilitate their discharge ; they deepen the navigable channel of the tidal river, except at a few points such as the Moyapur crossing ; and they carry down the deposit brought up by the flood tide in the dry season. Consequently, some information as to the volume and continuance of the preceding freshets should constitute an indispensable part of every yearly record of the condition and changes of the Húgli.

CHANGES IN THE RIVER HÚGLI BETWEEN HÚGLI POINT AND KANTABARIA.

General Features exhibited by the Early Charts.—The old charts of the seventeenth and eighteenth centuries show a deep channel all along this portion of the river, with soundings ranging between 5 and 12 fathoms ; shoals in front of Húgli Point and Kukrahati ; and a large detached shoal at the site of the present Diamond Sand, with a small, somewhat shallow channel between it and the right bank. The chart of 1813-14 furnishes similar indications, with from 4½ to 13 fathoms in the main channel, and shoals of under 3 fathoms in depth in front of, and to the south of Húgli Point, Plate 2, Fig. 8, and extending from the right bank in front of Kukrahati, more than half-way across the river ; whilst the Diamond shoal is partially indicated, with signs of a narrow inshore channel along the right bank.

The chart of 1836 shows depths of from 5 to 15 fathoms along the deepest line of the navigable channel, the greatest depths being found in the bends round Húgli and Diamond sands, and the shoalest water where the navigable channel crosses over from the right bank below Luff Point to the opposite bank, in front of Kukrahati shoal. Húgli shoal, with under 3 fathoms of water over it, extended from the left bank more than two-thirds of the distance across the river below Húgli Point, and rose to ¼ fathom below low-water in mid-river,

having a narrow channel, with depths of 2 to 3 fathoms, between it and the shore, Plate 2, Fig. 4. A similar shoal existed in front of Kukrahati, with a shallow inshore channel between it and the right bank ; but the shoal did not stretch quite half-way across the river within the limits of the 3-fathom contour, and it was rather lower than the Húgli shoal at its highest point, Plate 9, Fig. 1. Diamond Sand appears on the chart of 1836 as a detached bank ; but as the inshore channel separating it from the right bank had shoaled to $\frac{1}{4}$ fathom, it is possible that even at that period it would have appeared connected with the shore at the lowest low-water.

Lloyd's chart, as modified by Bedford in 1854, shows the Húgli shoal, at that date, with its 3-fathom contour extending more than three-fourths of the distance across the river at the extreme point, and without any defined inshore channel between it and the left bank, but lower generally than in 1836. From Luff Point to Kulpi, the modified chart is only a copy of the 1836 chart ; and the chart of the river accompanying Mr. Leonard's report, and dated March 1864, is merely a reduction of the 1836 chart above Kulpi.

Changes between Húgli Point and Kantabaria indicated by Recent Charts.— The chart of 1867-82 gives soundings ranging from 5 to 15 fathoms at low-water in the deepest channel along this part of the river. The 3-fathom contour, however, of the Húgli shoal, at the time of this survey, extended out about five-sixths of the distance across the river, and though cut into considerably towards the shore above and below, rose to 7 feet below low-water at its shallowest part, more than two-thirds of the way across the river from the left bank. The Kukrahati shoal extended rather further out than in 1836, and was more definitely united to the right bank below low-water ; but the depth of water over it was greater, with a minimum of $1\frac{1}{2}$ fathoms. Diamond Sand had become thoroughly connected with the right bank ; and a narrow spit extended from it down-stream in mid-river, owing to the flood tide having cut a wide blind channel into the lower part of the main bank between the spit and the shore.

In the large-scale survey of 1882-3, the soundings along the deepest channel of this section of the Húgli ranged from 4 to 16 fathoms, a break having occurred in the 5-fathom contour in the crossing over of the main channel between Luff Point and Hospital Point, in front of the Kukrahati shoal, where the 5-fathom depth was continuous in the chart of 1867-82. The 3-fathom contour, however, of the Húgli shoal did not extend out so far from the left bank as in the previous survey, though a small portion of the shoal rose nearly to the lowest low-water level in mid-river ; and the Kukrahati shoal had also been reduced in extent, Plate 4, Fig. 3, and Plate 10. The spit of Diamond Sand had become longer and more uniform in width, owing to the increased length and reduced width of the blind flood-tide channel ; but it did not extend out so far into the river as in the chart of 1867-82, or nearly so far as the detached Diamond Sand shown on the chart of 1836, Plates 9 and 10.

The chart of 1888, which appears to be a reduction of the general lines of the large-scale survey of 1882-3, with alterations where important changes had occurred in the interval, exhibits definite differences at the Húgli shoal

and Diamond Sand. The Húgli shoal, as defined by the 3-fathom contour, extended out nearly three-fourths of the distance across the river from the left bank in 1888, as in 1883, Plate 2, Fig. 5, and Plate 4, Fig. 3; but being considerably cut into towards the shore both above and below, it resembled somewhat closely in shape and in depth its condition as shown on the chart of 1867-82, though projecting less far into the river. The spit of Diamond Sand had become wider towards its lower end, and extended further out into the river than in 1883, though not so far as the detached sandbank of 1836; whilst the flood tide had cut somewhat more deeply into the bank, narrowing the spit at its junction with the main bank, Plate 9, Fig. 1.

The next complete survey of the Húgli between Húgli Point and Kantabaria is the recent large-scale survey; but two intermediate surveys were made below Luff Point, namely in April 1893 and in 1893-4. In April 1893, the 3-fathom contour of the Kukrahati shoal extended further out than in the chart of 1888; but a break still existed in the 5-fathom channel at the crossing in front of this shoal. The spit of Diamond Sand had returned approximately to its shape in 1883; but it extended rather further out than in 1888. There were signs also of a doubling back of the shoal below the spit within the 2-fathom contour, which may be attributed to the action of the strong flood tide emerging from the narrow neck at Kantabaria, after two seasons of low freshets.

In the survey of 1893-4, the Kukrahati shoal was very similar in form and extent to its state in 1883 and 1888; but the 5-fathom channel had again become continuous opposite the shoal, as in the survey of 1867-82, Plate 1, Fig. 3. The spit of Diamond Sand extended further out into the river than in the previous survey; and after the good freshets of 1893, the doubling back of the shoal had disappeared.

In the recent large-scale survey, the 3-fathom contour of the Húgli shoal bears a considerable resemblance in general outline to that of 1882-3, except that it extends further down-stream in front of the Eastern Gut, Plate 4, Figs. 3 and 4. In March 1896, the 3-fathom contour of the Kukrahati shoal extended further out than in April 1893; and the shoal was larger in area, and was more continuously connected with the shore between Luff Point and Buffalo Point than in the previous surveys. The 5-fathom channel, however, was continuous at the crossing in front of the Kukrahati shoal, as in the preceding chart of 1893-4, Plate 10. At Diamond Sand, the survey of March 1896 exhibits a remarkable doubling back of the end of the spit towards the channel, similar in character to the shape assumed by the 1 and 2-fathom lines of the shoal below in the chart of April 1893, and is doubtless due to the predominance of the flood tide after the exceptionally low and short freshets of 1895. This change of shape, having been at the same time accompanied by an extension of the spit down-stream into a narrower part of the river, owing to the washing up of the sand by the flood tide from the shoal below, has reduced considerably the minimum width of the low-water channel at this part from what it was in 1883. Moreover, though the spit does not extend further out from the right bank in the recent survey than in 1888, the low-water channel has been reduced, owing to the altered position of

the end of the spit, Plates 9 and 10; and the minimum width of the low-water channel, which was 3,900 feet in April 1893, was only 3,200 feet in March 1896. Nevertheless, the minimum width between the sandbank and the left bank was less in 1836 than now; whilst the minimum width of the 3-fathom channel has remained approximately the same in all the recent surveys. The folding back, however, of the extremity of the spit towards the channel has been accompanied by a notable advance of the lines of soundings into the channel above the protruding end of the spit, thereby contracting considerably the width of the deep channel round the bend, and in the lower part of Diamond Harbour. Thus the width of the 5-fathom channel opposite Diamond Harbour Creek has been reduced from a width of 4,000 feet, which it possessed in 1893, to 3,100 feet, and about a mile lower down from 2,600 feet to 1,950; and the width of the 3-fathom channel at the latter place was reduced from 3,500 feet to 2,300. On the other hand, this reduction in width has been accompanied by a decided increase in depth from Diamond Harbour Creek downwards, to beyond the end of the spit. As this encroachment of the sand on the navigable channel round the bend, and on the deep anchorage ground of Diamond Harbour, is evidently due to the recent predominating influence of the flood tide, an improvement is not likely to occur till the freshets regain their strength.

The earlier charts do not afford reliable information as to changes in the width of the river across the wide part at Diamond Sand; and probably erosion on the concave shore has been accompanied by accretion at the opposite side. It is, however, clear from the large-scale surveys that erosion has occurred along the left bank below Diamond Harbour Creek between 1883 and 1896, and that some accretion has taken place along the right bank adjoining Diamond Sand within the same period. There appears to have been only a slight increase in the width of the river opposite Luff Point and Buffalo Point since 1836; but the narrow neck at the entrance to the estuary opposite Kantabaria, which was evidently given much too great a width on the survey of 1813-14, has distinctly increased in width since 1836, though the recent increase in width of about 400 feet indicated by a comparison of the large-scale surveys of 1893 and 1896 appears exceptionally large.

Remarks on the Condition and Changes of the River Húgli from Húgli Point to Kantabaria.—The very deep channel which always exists between the mouth of the Rupnarain and Luff Point, Plate 3, Figs. 13 and 14, is due to the combined scour of the waters of the Húgli and the Rupnarain round the sharp bend made by the Húgli at the confluence of the Rupnarain, where the southward direction of the freshets and ebb tides of the Húgli drives the easterly flow from the Rupnarain against the Gewankhali bank, producing an erosion of the bank, which has averaged 9½ feet yearly since 1875. The shoal extending from Húgli Point has been formed, like the sandbanks at the points above, by the deposit of sediment towards the close of the freshets in the comparatively slack water of the wide channel beyond the influence of the main current running close along the right bank; but owing to the strong currents which always prevail along this reach of the river, except at low neaps in the dry season, the shoal is generally kept some feet below the lowest low-water, and is

only partially cut into at the back by the strong flood tides of the dry season.

The descending current, in being diverted from the right bank by Luff Point, necessarily forms a less stable, and consequently a shallower channel, crossing over towards Hospital Point on the opposite bank ; and the diversion of the current has led to the formation of Kukrahati shoal under the shelter of Luff Point. This shoal, which is the first place where the freshets, after issuing from the Rupnarain, have an opportunity of depositing some of their alluvium, probably advances somewhat each year towards the close of the freshets when their transporting power is reduced with their velocity ; but occasionally, as noted by Captain Petley each year between 1882 and 1889, and again this autumn, these Kukrahati lumps are deposited more than half-way across the river, encroaching upon the ordinary navigation tracks, till they are scoured away by the flood tides of the dry season. The somewhat erratic appearances of these lumps, which do not appear to coincide with any particular condition of the freshets, are probably due to the variations in the amount of erosion of the Gewankhali shore, or of the banks of the lower reaches of the Rupnarain. When the Kukrahati shoal extends some distance out from the right bank, the main current, being guided more directly across the river, usually forms a continuous 5-fathom channel, as shown on the charts of 1836, 1867-82, and 1896, Plate 10. On the contrary, when the Kukrahati shoal is small, the current is less confined in passing over from Luff Point to the opposite bank, and consequently the shoal at the crossing generally rises above the 5-fathom depth, as illustrated by the charts of 1883, 1888, and April 1893, Plate 9, though the chart of 1893-4, taken after the heavy rainfall of 1893, shows a good continuous 5-fathom channel at the crossing in spite of the smallness of the Kukrahati shoal at that period.

After passing the crossing opposite Kukrahati, a deep channel is maintained in the straight, narrowed reach below Hospital Point forming Diamond Harbour, where the descending current and the flood tide follow a fairly uniform course, throughout which the deepest soundings attain 10 fathoms and upwards, Plates 9 and 10. The depth is somewhat reducedby the interference presented to the current at the outlet of Diamond Harbour Creek ; but along near the concave left bank in the bend below, depths of 10 fathoms and upwards are generally maintained to beyond the end of the spit of Diamond Sand. Moreover, owing to the contraction of the river between Hospital Point and Buffalo Point, the long bend below, and the contraction of the river again at Kantabaria, the 7-fathom channel extends from below the Kukrahati crossing into Kulpi Roads, beyond which the increasing width of the estuary reduces the scour of the currents.

The main permanent changes in the Húgli between Húgli Point and Kantabaria, consist in the progressive widening of the river along the Gewankhali shore to Luff Point, and apparently a slight increase in width opposite Luff Point and Buffalo Point ; the erosion of the left bank in the bend below Diamond Harbour, accompanied by accretion on the opposite side ; and a widening out of the narrow neck at Kantabaria. The extension and connection

with the shore of the Húgli shoal and Diamond Sand are the natural results of the erosion of the opposite banks. The varying extent of the Kukrahati shoal, the fluctuations in depth at the Kukrahati crossing, and the recent shoaling of a portion of Diamond Harbour, are merely temporary changes depending on variations in deposit and scour, according to the changing conditions, and differences from year to year in the volume of the freshets. This portion of the river, moreover, though fluctuating in depth like the river above, Plate 3, Figs. 13 and 14, possesses a better depth than any other part, and shows the value of the additional discharge and tidal flow of the Rupnarain in maintaining the river below it.

CONCLUSIONSAS TO CHANGES IN THE RIVER HÚGLI ABOVE ITS ESTUARY.

The incompleteness of the large survey of 1813-14, the doubt with regard to the datum of the chart of 1836, and the uncertainty as to the period represented by the chart of 1867-82, limit the value of the indications of these charts, in comparison with the most recent surveys, as to the exact nature and extent of the changes which have occurred in the Húgli above its estuary during the present century. Two definite conclusions, however, may be deduced from the comparison of all the principal charts, namely, that the Húgli has become wider between its banks at most of the bends and also at some other places, especially at the sharp bend round Hangman's Point and Sankral Sand, across Fulta Sand, along the James and Mary reach, and in the Gewankhali bend ; and that the sandbanks and shoals formed under shelter of the points have been raised, extended, and more thoroughly connected with the shore below the point, at all the bends in the river from Ghusri Sand to Diamond Sand, Plate 2, Figs. 4 to 8, and Plate 4. The extension of these sandbanks is, indeed, a natural consequence of the increase generally in the width of the river ; and it is only subject to a temporary modification, when the failure of the freshets, as in 1895 and this year, gives the flood tide a greater influence for the erosion of the tails of the sandbanks. The evident extension of the central shoal in the James and Mary reach, and the raising of the shoal so that a portion emerges above the level of the lowest low-water, giving it a distinctly different aspect now to that presented by the charts of 1813-14 and 1836, even after due allowance for a difference in datum in the latter chart, Plates 2 and 4, are likewise the result of the considerable widening which has taken place in this portion of the river ; combined with a reduction in the fresh-water discharge from the Damuda ; but in this case, owing to the great divergence between the courses of the descending current and the flood tide, there is no tendency for the sandbank to become connected with the shore.

The widening of the river, and the resulting extension of the sandbanks below the points, are not in themselves proofs of a deterioration of the river ; for the growth of the sandbanks, under these conditions, merely serves to maintain the normal width and depth of the navigable channel, which are due to the configuration of the banks, and the average volume and duration of the freshets. A continuous erosion of the concave banks in the bends is, indeed, undesirable, for this increases the sinuosities of the navigable channel, and is liable to increase its

depth along the sharpened bend at the expense of its width ; but it would be quite possible, in a fairly stable river like the Húgli above Kantabaria, to arrest this action where it might threaten to be prejudicial to the navigable channel. The widening of the river undoubtedly reduces to some extent the scour of the freshets, so long as the river does not overflow its banks ; but, on the other hand, it increases the tidal capacity of the river, and facilitates the influx of the flood tide. The increased widening of the river in the bends tends, indeed, to produce irregularities in the tidal flow, which favour accretion ; but the raising and extension of the sandbanks by the freshets in proportion to the widening, rectify more or less these irregularities, and, though checking the direct tidal flow up the river, guide it to some extent into the navigable channel round the bends. The general widening of the river, accordingly, and the extension of the sandbanks below the points at the bends, though on the whole undesirable changes in the condition of the river, are not devoid of certain compensations, and have not hitherto, in most places, produced any appreciable deterioration in the navigable state of the river. Any widening, however, of the river where the channel crosses over from one bend to the next, such as has occurred to some extent in the Moyapur reach, and where the descending current and flood tide run along opposite sides of the river, as in the James and Mary reach, is distinctly prejudicial to the maintenance of the navigable condition at such places, by increasing the divergence between the two currents. In this respect, it must be acknowledged that there is distinct evidence of a change tending to a deterioration of the navigable condition of the Húgli at both these places ; whilst a comparison of the large-scale surveys of 1882-3 and 1896 shows that the enlargement of the river at these reaches is still in progress.

Deterioration at the Moyapur Crossing.—The deterioration in the navigable channel that must result from the widening of the river at the Moyapur crossing is evident enough, when it is remembered that in order to avoid an obstructive shoal at a crossing, the river should be narrower there than at the bends above and below, as is actually the case at most of the other crossings between Barrackpur and Kantabaria, Plate 2, instead of widening out, as the Moyapur reach does from the Ulabaria bend downwards, Plate 6. The great fluctuations, however, which occur, not merely with the seasons, but also from year to year according to the strength of the freshets, render it very difficult to prove from a comparison of the surveys and longitudinal sections of the navigable channel, that the anticipated deterioration has occurred ; for these surveys and sections only indicate the state of the crossing at one period in particular years, which may have been preceded by freshets of very different volume and duration. Records supplied me of the maximum and minimum depths in each of the navigable tracks of the Moyapur crossing, for every month from 1865 to 1894, appear to afford the only reliable basis for a comparison of the past and present condition of the Moyapur crossing. Grouping the yearly averages of depths in each track by decades, it has been found that the depth in 1865-74 exceeded the depth in 1875-84 in each of the tracks, with only one exception ; whilst the depth in 1875-84 exceeded the depth in 1885-94 in all the tracks, the actual average depths in all the tracks for each of the decades being 12 feet 11 inches, 12 feet 6 inches, and 10 feet 8 inches, respectively. This exhibits a gradual deterioration in

the average navigable depth at the Moyapur crossing, which was foreshadowed by the gradual enlargement of the river at that place ; and the deterioration indicated by the reduction in the average depth of the period 1885-94, is greater than that of the previous decade. As the Moyapur crossing exhibits, on the average, the greatest depth between April and July, and the least depth between September and December, it is evident that the freshets, by driving the crossing point down-stream and thereby increasing the divergence of its channel from that of the flood tide along the opposite bank, and by depositing sediment in the flood-tide channel beyond the main stream of the descending current, reduce the depth over the crossing, so that the bar across the navigable channel is highest in October or November ; and the shoal is only lowered again to its previous depth when the flood tide regains its predominance, especially after the setting in of the south-west monsoon. Accordingly, since the predominance of the flood tide is more favourable to the maintenance of the depth over the Moyapur crossing than powerful freshets, the greater reduction in the average depth over the crossing in 1885-94, as compared with 1875-84, than in 1875-84 as compared with 1865-74, may be due to the circumstance that the freshets were, on the average, higher in the third decade than in the second, and lower in the second decade than in the first.

The general shoaling in the tracks over the Moyapur crossing, as obtained from the depths given in the records, amounts to an average of $2\frac{1}{4}$ feet in twenty years. This is the nearest approximation that can be arrived at with the data available, and will doubtless be modified by subsequent records ; and it is probable that the decrease in depth indicated is somewhat too large, as the freshets during the period 1885-94 were somewhat higher, on the average, than during 1865-74, and therefore the conditions rather less favourable in the last period than in the first. The reductions in depth, however, in the several tracks show a considerable concordance ; and it is certain that a widening of the river at the crossing, in the absence of any compensating changes, must result in a reduction in depth. Even assuming that the shoaling may only average about 9 inches in ten years, this is a reduction in depth which could not be allowed to continue unchecked.

The Moyapur crossing possesses the advantage that its bar attains its greatest height before the freshets have subsided, and becomes lower before the river falls to the ordinary low level of the dry season. The difficulties also of navigating the Moyapur crossing have been minimised, like those of all other obstacles in the river and estuary, by the frequent river notices issued during recent years, by the present Deputy Conservator, for the guidance of the pilots. The impediment, moreover, hitherto presented by the Moyapur shoal to the passage of vessels down the river, has been overshadowed by the more serious obstacle to navigation lower down, caused by the bar across the Eastern Gut in the James and Mary Reach ; but the full benefit of a due improvement in the available depth of the James and Mary reach could not be attained without being accompanied by a lowering of the shoal at the Moyapur crossing.

Condition of Fulta Reach.—The channel of the Húgli between Garden Reach and Brul Sand consists of a fairly well-defined succession of bends and crossings ; but below Brul Sand, its course becomes irregular, owing to the absence of uniformity in the relative positions of the points and bends, and the disturbing influences produced on the flow of the river by the influx of the Damuda and the Rupnarain. The descending current, which forms the navigable channel, after passing round the bend alongside Brul Sand, is directed as usual across the river before reaching the point at Pukuria ; but instead of meeting with a concave bank along the opposite side, facing Pukuria Point, to direct its course, as at the bends above, it encounters Fisherman's Point. Though the projection of this point is too slight to divert the main current away from the concave bank below it, nevertheless it deflects a portion of the current towards Dhaja Point and Fulta Sand, which has led to the formation of the minor channel at the back of Fulta Sand previously referred to, indicated on all the charts up to the survey of 1882-3, Plate 4, Fig. 3. The growth upstream of Fulta Sand and its surrounding shoal, under the predominating influence of the flood tide after the feeble freshets of 1895, has so shoaled this channel at its upper end that only traces of it are found in the survey of 1896, Plate 4, Fig. 4 ; but the partial deflection of the current by Fisherman's Point has assisted the strong flood tide running through the contracted channel opposite Fulta Point, in preventing Fulta Sand from being joined to the right bank at low-water like the sandbanks at the bends above, and has kept the main channel, following the concave bend in Fulta Reach, narrower for the most part, and shallower than at the other bends, Plates 2 and 4, and Plate 3, Figs. 13 and 14. The shoaling of the minor channel alongside Dhaja Flat since 1883 has been accompanied by an improvement in the navigable channel alongside the left bank in Fulta Reach, in spite of the considerable widening of the river which appears to have occurred at this part since the survey of 1882-3, Plate 4, Figs. 3 and 4. As the enlargement of this reach must have, indeed, promoted the increased connection of Fulta shoal with the right bank, resulting in an improvement of the main channel, it cannot be regarded as a deterioration in respect to this portion of the river ; for an improved navigable channel round the bend is preferable to a bifurcated channel with a central shoal, even though the existence of a minor channel at the back of Fulta Sand afforded a straighter run for the flood tide. As soon, however, as Fulta Sand becomes sufficiently extended and raised to be permanently connected with Dhaja Flat at low-water, the erosion of the concave bank opposite should be stopped ; for a continued cutting away of the left bank in Fulta reach would increasingly divert the course of the navigable channel from the direct run of the flood tide, which would promote the extension of the blind flood-tide channel at the back of Fulta Sand after low freshets, and thereby lead to the narrowing and shoaling of the navigable channel, Plate 4, Fig. 4.

Deterioration of the James and Mary Reach.—Owing to the confluence of the Damuda on the right bank, just above Fulta Point, at right-angles to the course of the Húgli, the descending current of the Húgli is pushed towards the left bank round Fulta Point, and on towards Ninan, by the freshets of the Damuda in the rainy season, and by the outflow of the ebb tide from it in the

dry season. The course assumed by the combined currents of the Húgli and the Damuda on emerging from the narrow neck at Fulta Point into the James and Mary reach, is the resultant of the direction in which the current of the Húgli approaches the neck, its volume, and the volume of the Damuda joining it approximately at right-angles. The direction of approach of the flow of the Húgli is evidently modified by changes in the channels of Fulta reach; for with a good secondary channel at the back of Fulta Sand, the direct current through it would be strong; whilst an improvement in the navigable channel round the bend causes a larger proportion of the discharge of the Húgli to follow this course, which, on bending round towards Fulta Point, is more directly opposed to the current of the Damuda than the straighter flow between Dhaja Flat and Fulta Sand. Accordingly, the discharge of the Damuda has a greater influence in directing the discharge of the Húgli towards Ninan when the channel at the back of Fulta Sand is fairly deep, than when it has shoaled and the main channel has correspondingly improved; and, consequently, a more central deep channel is formed by the combined currents below the neck into the James and Mary reach, when the main channel round the bend of Fulta reach has improved at the expense of the minor, direct channel at the back of Fulta Sand. The formation by the freshets of a central channel in the James and Mary reach, extending from the deep hollow always maintained by the concentrated current opposite Fulta Point, is generally unfavourable for navigation, owing to the shifting nature of such an undirected channel in the midst of shoals, and the tendency of the current rushing through the neck, to deposit sediment when its velocity is checked in the middle of the wide reach, towards the close of the freshets. This results in the formation of a shoal near Ninan, between the deep channel extending from the neck, and the inshore channel always maintained along the left bank by the general set of the descending current, from near Ninan to Húgli Point, Plate 7, Fig. 3. On the contrary, when the outflow from the Damuda is sufficiently powerful in relation to the discharge of the Húgli, to push the current over to the left bank below Fulta Point, the current is guided round the concave left bank past Ninan, and forms a continuous channel into the Eastern Gut, Plate 4, Fig. 3. A bar, accordingly, is more liable to be formed at Ninan when the channel at the back of Fulta Sand is shoaled up, and the current of the Húgli consequently more directly opposed to that of the Damuda. The practical obliteration, therefore of the channel at the back of Fulta Sand, which has occurred since the survey of 1882-3, probably after the low freshets of 1883 and 1884, being shown on the chart of 1888 as well as in the recent survey, Plate 2, Fig. 5, and Plate 4, Fig. 4, has been prejudicial to the maintenance of the Ninan channel. Moreover, the erosion in progress in the concave portions of the left bank of the Húgli above and below Fulta Point, exercises an unfavourable influence on the Ninan channel, by causing the current along the navigable channel in Fulta reach to follow a course near Fulta Point more directly in opposition to that of the Damuda, and by making the bank below the point recede gradually further away from the influence of the Damuda. The shoaling up, accordingly, of the channel along Dhaja Flat, so far as it can be considered permanent, and the progressive erosion of the left bank above and below Fulta Point, are causes of a distinct deterioration

in the Ninan channel of the James and Mary reach, and to some extent explain why the Ninan bar, which according to Captain Petley, had not been an obstruction to the passage of vessels prior to 1885, occasioned delays to navigation in that year and some subsequent years.

As the basins of the tributaries of the Bhagirathi and the Damuda adjoin one another, the discharges from them may be fairly considered to vary proportionately with the rainfall over that district of Bengal from year to year. Accordingly, if the Damuda delivered all its flood discharge into the Húgli at its outlet, its action in diverting the waters of the Húgli towards the left bank at Fulta Point and below, would remain fairly constant throughout the freshets, whether high or low, except for such modifications, as differences in the proportionate influx from the Ganges into the Nadia rivers might introduce. Owing, however, to the restriction of the channel of the Damuda near Ampta, the breaches formed in the embankments above, and the subsequent removal of long lengths of embankment, most of the flood discharge of the Damuda leaves its channel; and only a discharge of 35,000 cubic feet per second according to Mr. Lees, or 100,000 cubic feet according to Mr. Leonard, finds its way into the Húgli above Fulta Point. So long, therefore, as the rainfall is not sufficient to raise the discharge of the Damuda above the volume which can pass through the channel at Ampta and flow into the Húgli opposite Fulta Point, the Damuda exercises its full proportionate influence in directing the current of the Húgli towards Ninan. Directly, however, the rainfall produces a discharge in excess of the maximum quantity which the Damuda can carry down past Ampta to its outlet, the flow from the tributaries of the Bhagirathi is increased without any further addition to the outflow of the Damuda at Fulta. Owing, accordingly, to this peculiarity in the discharge of the Damuda into the Húgli, limiting its volume to a maximum much below the flow off its drainage area in seasons of heavy rainfall, the Damuda must have much more influence in directing the current of the Húgli towards Ninan in seasons when the rainfall is small, than in seasons of heavy rainfall. From this it follows that, subject to modifications introduced by changes in the channels and sands of Fulta reach, the channel formed by the combined freshets of the Húgli and the Damuda in the upper portion of the James and Mary reach, ought to be directed towards the left bank in seasons of small rainfall, and the Ninan channel remain good, and should assume a more central course in proportion somewhat to the amount of rainfall, leading to the raising of the shoal in the Ninan channel towards the close of the freshets after seasons of large rainfall. Now according to Captain Petley's yearly reports on the condition of the Húgli, the Ninan channel was in a good state in the winters of 1884-5 and 1892-3, it changed from a bad condition to a good one during the winter of 1891-2, and it gave no trouble in the winter of 1895-6; whilst the rainfall over the part of Bengal in the neighbourhood of the basins of the tributaries of the Bhagirathi and the Damuda, averaged 38 inches in 1884, 42 inches in 1892, 45 inches in 1891, and 38 inches in 1895, the mean annual rainfall of that district being about 52 inches. On the contrary, the condition of the Ninan channel was bad in the winters of 1885-6, 1886-7, 1890-1, 1893-4 and 1894-5; and the rainfall of the rainy seasons preceding these winters amounted to 60 inches in

1885, 65 inches in 1886, 64 inches in 1890, 63 inches in 1893, and 57 inches in 1894. These statistics furnish evidence that the influence of the Damuda, in directing the channel below Fulta Point towards Ninan, varies inversely with the rainfall, as deduced from the consideration of the peculiarity of its flood discharge; and, so far as the records extend, they lead to the conclusion that, under the existing conditions of the Fulta and James and Mary reaches, the state of the Ninan channel at the close of the freshets largely depends on the amount of the preceding rainfall. The Ninan bar generally attains its greatest height on the abatement of the freshets in November, and is gradually lowered by the uniform action of the ebb tide throughout the dry season, during which the Damuda exercises its influence regularly in proportion to its tidal capacity in relation to that of the Húgli. The difference in form that may be assumed by the deep channel between Fulta Point and Ninan after a season of average rainfall, when the Ninan channel maintained a fair average depth, and after the beneficial action of the ebb tide during the dry season, as compared with its state after a season of rather high rainfall and soon after the close of the freshets, is indicated by Plate 7, Figs. 2 and 3.

The chart of 1813-14 shows a wide, continuous 3-fathom channel between Fulta Point and Nurpur, Plate 2, Fig. 8; and at that period there was a fair channel shown at the back of Fulta Sand; and the survey was probably preceded by low freshets, judging by the general shallowness of the longitudinal section obtained from it, as compared with the sections taken from the later surveys. The chart of 1836, on the contrary, which indicates a much shallower channel generally at the back of Fulta Sand, with soundings of only $1\frac{1}{4}$ to $1\frac{1}{2}$ fathoms in it at low-water, exhibits a bar between Ninan and Nurpur with only 15 feet of water over it at low-water, when there was a 3-fathom channel throughout the Eastern Gut, Plate 2, Fig. 4. The navigable channel, indeed, of the James and Mary reach in 1836 bears a remarkable resemblance to the channel of January 1895, with the sole exception that the Ninan bar at the latter date had only 11 feet of water over it; for in both cases there was a deep, somewhat central channel below Fulta Point, a bar between this channel and the Eastern Gut, and a 3-fathom channel over the crossing at the lower end of the Eastern Gut, Plate 2, Fig. 4, and Plate 7, Fig. 3. The unusually good condition of the navigable channel on the chart of 1836 renders it probable that the survey was preceded by high freshets, like the survey of January 1895; and the better depth over the Ninan bar in 1836 might very naturally be due to the influence of the remnant of the minor channel at Fulta, to the floods of the Damuda being still restricted at that time by embankments, and possibly to the survey of 1836 having been made later in the dry season than January. The channel at the back of Fulta Sand appears to have opened up again subsequently to 1836, for it is shown more open and with a much improved depth on the chart of 1867-82; and a corresponding improvement in the Ninan channel is indicated on this chart. The channel at the back of Fulta Sand was maintained up to 1883, though with a much diminished width; and a wide 3-fathom channel extended from Fulta Point, past Ninan, to Nurpur, Plate 4, Fig. 3; whilst the chart of 1888 exhibits a shoal extending from Dhaja

Flat to Fulta Sand without an intervening channel, and a deteriorated condition of the Ninan channel, Plate 2, Fig. 5.

The primary cause, accordingly, of the obstruction occasionally presented to navigation by the Ninan bar, after the close of the freshets, since 1885, appears to be the shoaling of the channel at the back of Fulta Sand ; and the secondary cause is the effect of high freshets in forming a central channel below Fulta Point away from Ninan, leading to the formation of a shoal between this channel and the Eastern Gut as the freshets subside. The influence, indeed, of heavy rainfall in making the freshets of the Húgli overpower the outflow of the Damuda, thereby leading to the shoaling of the Ninan channel, doubtless produced its effects previously to 1885, more especially after the embankment of the Damuda was abandoned; but the direct flow of the Húgli through the minor channel prevented the variations due to a large rainfall producing their full effect, and forming an obstruction to navigation. Now, however, the reduction of the direct current has so intensified the effects of a heavy rainfall, that a high Ninan bar seems to have become a natural sequel to a very rainy season. It is possible that the channel at the back of Fulta Sand may open out again, considering that it enlarged considerably from its deteriorated condition subequently to 1836 ; and in that case the Ninan bar might be expected to revert to the comparatively low level it maintained previously to 1885. There is, however, one source of deterioration in progress, and another in prospect, which would probably render the opening out of the minor channel, if it should occur, less beneficial to the Ninan channel than formerly, namely the erosion of the concave portions of the left bank immediately above and below Fulta Point already referred to, and a reduction in the discharge of the Damuda. Mr. Horn, from an inspection of the Damuda last spring, considers that, though there appears to have been little change in the amount of water passing from the Damuda to the Rupnarain during the last thirty years, the water passing down the Damuda to the Húgli is likely to be greatly reduced in the next thirty years, owing to the silting up of the bed of the Damuda, which is in progress just below the Begooa breach. This further reduction in the flood discharge of the Damuda into the Húgli at Fulta, accompanied as it would be by the silting up of the channel which serves as a tidal reservoir in the dry season, would greatly reduce the influence of the outflow from the Damuda in pushing the current of the Húgli towards Ninan ; and therefore the beneficial action on the Ninan channel of a stronger direct current of the Húgli through the neck at Fulta Point, resulting from a re-opening of the channel at the back of Fulta Sand, would be to some extent neutralised. It seems, however, more probable that the minor channel will not open out again to the same extent as formerly, judging by the general tendency of the sandbanks of the Húgli to become raised and extended with the increase in width of the river. In this event, and especially if Fulta Sand continues to extend and becomes eventually connected at low-water with Dhaja Flat, there is every prospect that the Ninan bar will continue to form an obstruction to navigation at the close of high freshets, and that its condition will tend to deteriorate rather than to improve. The changes, accordingly, which have occurred in Fulta reach, the widening of the Húgli in progress near Fulta Point, and

the prospective reduction in the discharge of the Damuda, appear likely to constitute a permanent deterioration in the Ninan channel of the James and Mary reach.

In the lower portion of the James and Mary reach, two channels on opposite sides of the river, known respectively as the Eastern and Western Guts, appear upon all the charts, with a central shoal between them. The Eastern Gut is the channel formed by the freshets and ebb tide along the left bank, for the curving round of the left bank below Anchoring Creek brings it in face of the direct course of the current flowing through the neck at Fulta Point, which, consequently, impinges upon it when high freshets form a central channel, or comes round to it past Ninan during low freshets and in the dry season. A channel, accordingly, always exists running close alongside the left bank from below Ninan to the slight projection of Nurpur Point, where after being somewhat deflected, it continues near the left bank past Húgli Point, and then crosses over the river to the deep channel along the Gewankhali shore. The Eastern Gut naturally becomes shoaler where the current forming it after passing between the central shoal and the left bank, emerges into the open river, and has to cross the Húgli shoal extending from Húgli Point, so that a bar of varying height is always found at the crossing, which is raised by the conflicting action of the flood tide in the dry season, Plate 7. The Western Gut is formed by the flood tide which rushes up the verp deep, fairly straight channel above Diamond Harbour Creek in the dry season, and splits near Mornington Point, where a portion flows straight into the Rupnarain, and the larger part runs up along the right bank of the Húgli, forming a deep channel for about a couple of miles towards Shipgunj Point, beyond which the current spreads out over the river and the channel becomes undefined. A secondary short blind channel is also generally formed as the dry season advances, branching off from the deep channel opposite Gewankhali, and cutting into the central shoal in mid-river, which it pushes up-stream, Plate 4, Fig. 3, and Plate 7, Figs. 1 and 2.

The central sandbank between the Eastern and Western Guts, and the variable shoals above are the natural results of the action of a rapid sediment-bearing current emerging from a narrow neck into a wide reach, which not only has been deprived of a portion of its discharge by the diversion of the greater part of the flood waters of the Damuda into the Rupnarain, but is continually being widened by the erosion of the freshets on the left bank, and of the flood tide on the right bank. This widening of the reach is necessarily accompanied by a corresponding enlargement and raising of the central sandbank ; and an extension of the shoals above. Thus there was a minimum depth over the central shoal, at low-water, of $1\frac{1}{4}$ fathoms on the survey of 1813-14, 1 fathom on Ross' survey of 1826, and the same on Lloyd's chart of 1836, Plate 2, Fig. 4, 3/8 fathom on Obbard's survey of 1857, Plate 7, Fig. 1, and 1/8 fathom on Laycock's survey of 1865. Two patches of the shoal emerge at low-water, for the first time, on the chart of 1867-82 ; and on all the subsequent surveys from 1875 to the present time, a sandbank of variable size and shape appears above the lowest low-water in mid-river, low down or higher up the reach according as the period of the survey was

early or late in the dry season, Plate 7. Notwithstanding, however, the changes in the sandbank, the cross section of the river experiences less variation opposite Hope's Obelisk, as well as in the narrow neck at Fulta Point and below Húgli Point, than opposite Ninan and Nurpur, owing to the much greater stability of the Eastern and Western Guts in position than the channel extending from Fulta Point, Plate 8, Figs. 1 to 5. The notable extension of the shoals which has gradually taken place in the James and Mary reach, is well illustrated by a comparison of the charts of 1813-14 and 1888, Plate 2, Figs. 5 and 8.

The Eastern Gut being the channel of the freshets and ebb tide, is, as usual, generally the navigable channel; and it attains its best available depth about November, after it has been scoured by the freshets, and is shoalest about July at the close of the predominance of the flood tide. The Western Gut, on the contrary, is deepest about June and shoalest in October or November, being scoured out by the strong flood tides of the dry season, and silted up by the freshets. Though, however, the Eastern Gut is scoured out by the freshets, and the Western Gut by the flood tide, the alterations of the channel at the upper end of the reach, and the condition of the Húgli shoal below, introduce complications. Accordingly, though in the months near the close of the freshets after a season of very small rainfall, the available depth of the Eastern Gut is generally below the average for those months,as towards the end of 1877, 1884, and 1895, and the depth in the Western Gut above the average, and still more the depth in the Eastern Gut is large after seasons of specially heavy rainfall, such as 1879, 1886, and 1890,it is not possible to state as a general proposition that the Eastern Gut will be deep after freshets exceeding the average height, and shallow after low freshets. The probability, however, is that the Eastern Gut will be in a good state at the close of high freshets, which, on the contrary, are prejudicial to the Ninan channel; and therefore it was natural that, whilst the Ninan channel was bad towards the end of 1886, 1890,and 1894, the Eastern Gut was deep. The Western Gut has been deteriorated by the widening of the river and the extension of the central shoal, for it has been thereby removed further from the ebb-tide channel; so that whereas towards the close of the last century it was used in several years as the navigable channel,* it has for many years past been far too shallow at its upper end to be suitable for navigation; and its adoption for a short period last winter, on the sudden shoaling of the Eastern Gut after the low freshets of 1895, as the channel for the passage of vessels, was quite exceptional, Plate 5, Fig. 27, and Plate 7, Fig. 4. Its maximum depth, indeed, between 1875 and 1894 was 10 feet in 1877; and its minimum depth has often fallen to zero at the lowest low-water. The Eastern Gut, on the other hand, has reached a maximum depth of 25 feet between 1865 and 1894; and its minimum depth has only on one or two occasions fallen to zero in any of the tracks. The average depth, moreover, in the Eastern Gut, as obtained from the monthly records of maximum and minimum depths, has increased from 11 feet 3 inches in 1865-74 to 11 feet 10 inches in 1885-94; whereas the average depth in the Western

* "Memorandum by J. Obbard upon the past and present condition of the River Hooghly," appended to "Memorandum on the River Hooghly," by H. Leonard, Calcutta, 1864, pp. 27 and 28.

Gut has decreased from 2 feet 5½ inches in 1875-84, to 2 feet 3 inches in 1885-94. The Eastern Gut, accordingly, though exhibiting great seasonal variations in depth over its bar, and occasional rapid fluctuations near the beginning and close of the rainy season, such for instance as occurred in November 1895, appears to have fully maintained its average depth between 1865 and 1894, the descending current being uniformly guided by the curving left bank between Anchoring Creek and Húgli Point, and directed across the bar formed by the flood tide running up at right-angles to the outlet of the Eastern Gut, over the Húgli shoal. If the extension of Fulta Sand should continue, and the sandbank become connected with Dhaja Flat and raised considerably, so as to concentrate the main current of the Húgli into the navigable channel round the bend, and if at the same time the discharge of the Damuda should be greatly reduced and its channel silt up, the current through the neck at Fulta Point would follow a more westerly direction and might open up the Western Gut in place of the Eastern Gut. The untrained Western Gut, however, in crossing the river between shoals in the centre of the reach, even when it has been opened out by a branch off the upper channel, or owing to an obstruction to the efflux of the ebb tide through the Eastern Gut, as occurred towards the end of November 1895, Plate 7, Fig. 4, has never remained very stable, or been kept open for a long period, as there is nothing to keep it in position amongst shifting sandbanks; and the ebb tide tends gradually to resume its ordinary course along the left bank, which restored the normal depth of the Eastern Gut last March. It appears, therefore, very doubtful whether the possible changes outlined above would improve the navigable channel through the James and Mary reach ; and if these changes should eventually progress so far as to direct the descending current below Fulta Point against the right bank above Shipgunj Point, the current would probably be deflected by the point across the river again towards the left bank, following a course which could not lead to the formation of a stable and deep channel. Accordingly, beyond the possible opening out again of the channel at the back of Fulta Sand, there appears to be no prospect of any change likely to result in an improvement of the present navigable condition of the James and Mary reach. The navigation of this reach, moreover, whilst still exposed as formerly to the regular shoaling of the Eastern Gut bar towards the end of the dry season, with occasional abrupt reductions in depth, and with apparently less prospect than in former times, in the widened river, of relief by the adequate opening out of the Western Gut, which has only occurred once in the last thirty-two years, has become liable since 1885 to be impeded in addition by the shoaling of the Ninan bar at the close of seasons of high freshets. The Eastern Gut, indeed, though the most awkward and changeable part of the river in regard to its bar, is the only portion of the James and Mary reach which does not appear to have hitherto, on the whole, changed for the worse ; for the sandbanks and shoals in mid-river have been raised and extended, the Western Gut has deteriorated, and the Ninan bar has developed into a periodical impediment to navigation.

Changes in the Upper Part of the River Húgli.—Another large-scale survey of the Húgli between Shamnagar and Cossipur would have to be made, for comparison with the survey of 1885-6, before any reliable conclusions could be

drawn as to the changes in this portion of the river. A large-scale survey also of the river from Cossipur to Howrah Bridge is needed to compare with the survey of 1882-3, together with the survey above Cossipur, in order to enable a definite deduction to be drawn as to the cause and effect of the extension of Ghusri Sand ; for this change may be due to alterations in the river above or below, as well as to the influence of the freshets or the flood tide.

The deterioration of the portion of the Húgli between Howrah Bridge and Shalimar Sand, which is undoubtedly due to the reclamations, has probably reached its limit ; but the much-increased fluctuations in depth, and in the extent of the shoals in the vicinity of Kidderpur, according to the height or lowness of the freshets, are likely to continue so long as the projecting reclamation, narrowing the river above the head of Shalimar Sand, remains.

The course of the navigable channel off Munikhali Point was distinctly more tortuous in 1780-1 than in 1836 or at the present time, owing to the protrusion of the Point into the course of the descending current, which invariably produces an irregularity in the channel, as noticeable at the present time off Fort Point in Hastings reach, and off Nurpur Point in the James and Mary reach, Plate 2, Figs. 4 and 7, and Plate 4. It appears, however, from the records quoted by Mr. Obbard in his Memorandum, that this channel had been considerably shoaler in 1770 than shown on the survey of 1780-1, and that in 1795 a ridge formed across the channel from the tail of Sankral Sand to the head of Munikhali Sand, with a depth over it of only 3 fathoms at half ebb, and that Munikhali Point was much washed away. These changes evidently led to an improvement in the course of the channel, which has been fairly maintained ; and the channel was much shoaler on some occasions in the last century than it is now. Owing, however, to the very sharp bends in the river round Hangman's Point and Munikhali Point, and the continued erosion of the concave right bank opposite Sankral Sand, this part of the river will require watching ; and it may prove expedient to protect the bank where the greatest cutting away takes place.

Suggestions about Observations of Changes in the River Húgli.—In order to take note, and to preserve records of the changes in the river above its estuary, it would be advisable to make large-scale surveys of the river at intervals of about ten years, plotting them always to the same scale as the preceding survey, and stating on each sheet the period at which that part of the survey was taken, as has been done on the sheets of the recent survey, but which was omitted in the survey of 1882-3 ; for it is very important for purposes of comparison, in a river like the Húgli, to know the month to which the survey relates. Complete surveys of important reaches of the river subject to change, such as Moyapur, the James and Mary, and Luff Point to Kantabaria, should be taken, as at present, more frequently. Moreover, in order to observe more closely changes in the bed of the river at shorter intervals, to obtain absolutely comparable cross sections, and to ascertain exactly the extent and position of the erosion of the banks, it would be well to have permanent marks placed at a little distance from the edge of the river, at selected spots on each side, from

which cross sections of the river along identical lines could be taken at suitable periods. These cross sections would furnish more reliable information as to changes in width and depth, and afford a clearer insight into the alterations in the bed of the river, especially if taken during the freshets as well as in the dry season, than can possibly be obtained from the soundings on the large-scale surveys, taken at long intervals apart, and along lines which often do not quite correspond.

CHANGES IN THE HÚGLI ESTUARY.

The River Húgli, after passing Diamond Sand, flows through the narrowed neck at Kantabaria, having a width of $1\frac{1}{3}$ miles between its banks, and emerges into the rapidly expanding estuary which attains a width of about 5 miles opposite Middle Point, only $8\frac{1}{2}$ miles below Kantabaria. The estuary maintains a very similar width along the next 6 miles down to Mud Point, below the entrance to Channel Creek; and then enlarging irregularly in front of Saugor Island, it has a width of nearly 8 miles opposite Khijiri, about 8 miles further down, below which it widens out rapidly to 13 miles at its outlet opposite Middleton Point, at the south-western corner of Saugor Island, about 10 miles below Khijiri.

The navigable channel through the Húgli estuary exibits a marked contrast to the navigable channel in the river above; for whereas the river channel, being confined between banks, is directed, for the most part, in a fairly definite, stable course, the channel through the estuary is much less defined and generally wider, it is liable to split up into branches, and it is free to shift its course amongst the sandbanks encumbering the estuary, following the direction of least resistance to the currents maintaining it. The instability, however, of the estuary channel as regards direction is accompanied by a much greater uniformity in depth than the river channel, as shown by a comparison of the longitudinal sections of the Húgli below Kantabaria with those above, Plate 3, Figs. 13 and 14.

Channels of the Húgli Estuary shown on the Early Charts.—The chart of the Húgli in the early part of the eighteenth century shows the navigable channel keeping close along the eastern shore, from Kantabaria past Rangafala to the entrance of Channel Creek, which having crossed, it diverged towards the west a little above Mud Point, and passing over to the opposite shore below Khijiri, the buoyed channel kept along the western shore from Kaukhali, past the mouth of the Rasulpur, to the outlet of the estuary, finding a passage to sea to the east of the Western Brace, Plate 12, Fig. 1. A central channel in about the position of the present Western Channel is described as "the new passage out;" but though it was buoyed up to Hijili, where it joined the regular channel, no soundings are given except along the lower half. The Eastern Channel running alongside Saugor Island, described on the chart as "the old passage out," was barred off from the channel in the upper estuary by a shoal stretching across from Cox's Island, off the South Bluff of Saugor Island, to the Long Sand which is represented as extending from the Eastern Sea Reef up to opposite Hijili. The soundings give a minimum of 3 fathoms near Rangafala, in the middle of the crossing off

Mud Point, and near Hijili, falling to 2 fathoms at the outlet of the estuary before reaching deep water beyond. The deepest soundings in the channel were 7 to 9 fathoms between Rangafala and Channel Creek, and 4 to 5 fathoms along the greater part of the crossing, and down to a little below Hijili; and after crossing the long shoal of between 2 and 3 fathoms near the outlet of the estuary, the depth gradually increased from 4 fathoms up to 10 fathoms opposite the end of the Western Brace.

The next chart, of 1768-70, shows a central channel to the west of the Rangafala shoal, as well as a narrower, and somewhat shallower channel along the former route, close to the eastern shore ; and these channels joining below the shoal, passed in front of the entrance to Channel Creek, and branched off again near Mud Point into two channels leading to the sea. One channel crossing over to the western shore at Khijiri, followed a course very similar to that of the earlier chart down to a little below the mouth of the Rasulpur, where adopting a more easterly direction corresponding to " the new passage out " of the previous chart, it found an outlet to the sea between the Eastern Sea Reef and the Long Sand, described on the chart as the "passage out ;" and the other channel passed down by Saugor Island, and following at the lower part the line of the Bedford Channel, passed through Saugor Roads into the Eastern Channel. Both channels had a depth of only $2\frac{1}{2}$ fathoms at their upper end opposite Mud Point ; but though the Western Channel appears to have been used as the navigable channel, it was much more circuitous, and had a more variable depth, with soundings ranging from 2 to 10 fathoms, than the Eastern Channel, Plate 9, Fig. 2.

The survey of 1813-14 shows the main channel still passing along the western side of Rangafala shoal, but considerably nearer the eastern shore than in the previous survey, on account of a considerable reduction in the Rangafala shoal, which had also shifted nearer the shore, narrowing and shoaling the inshore channel; whilst the outer shoal off Balari, described in the previous chart as the Western Flat, had extended. Below Rangafala shoal, the main channel approached the eastern shore near Middle Point, and passing close to Silver Tree and Mud Point, it went across the estuary ; and after approaching the western shore within a mile and a half of Khijiri Point, it turned back again towards Black's Point on Saugor Island by the Minto Channel, and passing through Saugor Roads it found an outlet to the sea by the Eastern Channel, Plate 9, Fig. 2. The navigable channel, accordingly, at that period was much more circuitous than the channel indicated on either of the previous surveys referred to. The least soundings given in the deepest channel are $3\frac{1}{2}$ fathoms in the outer Rangafala Channel, $3\frac{1}{4}$ fathoms between Rangafala shoal and Mud Point, $3\frac{3}{4}$ fathoms in the scanty figures in the crossing from Mud Point to Khijiri, only $3\frac{1}{2}$ to $2\frac{1}{4}$ fathoms along the greater part of the Minto Channel in the second crossing down to opposite Black's Point, beyond which there is only one sounding not exceeding 3 fathoms to the end of the survey just above Middleton Point. The two bars across the Minto Channel, with depths over them of less than 3 fathoms at low-water, were each about $1\frac{1}{4}$ miles wide, Plate 3, Fig. 13.

Chart of the Húgli Estuary of 1836.—Lloyd's chart of the estuary made in 1836, though not accurate enough as regards the outlines of the sandbanks,

to afford a proper comparison with recent charts, gives indications of a much more detailed survey than any of the earlier charts; and, accordingly, the shore-lines, islands, low-water lines, and 3-fathom contours are shown in red over the reduced chart of 1888, Plate 9, Fig. 1.

In 1836, the deepest navigable channel came close in-shore at Kulpi, where the Rangafala shoal as defined by the 3-fathom contour began; and keeping between the shore and the Rangafala shoal to its termination a little above Middle Point, the channel continued along the shore down to Silver Tree Obelisk. The channel then, after crossing the entrance to Channel Creek, diverged a little above Mud Point, across the estuary by the Mud Point Channel to Khijiri Point; and after keeping near the western shore to below Kaukhali lighthouse, it passed again across the estuary by Lloyd's Channel into Saugor Roads, whence it found an outlet to the sea by the Eastern Channel, Plate 9, Fig. 2. The channel of 1836, accordingly, bore a considerable resemblance to the channel of 1813-14 in general direction; but the inner Rangafala Channel had again become the deepest channel; and though the direction of the first crossing from Mud Point to Khijiri was very similar on both charts, the channel of 1836 came much closer to Khijiri Point than the channel of 1813-14; and Lloyd's Channel went more to the south, and passed more diagonally across the estuary than the Minto Channel.

There was another channel between Kantabaria and Mud Point outside Rangafala shoal, which was much wider and more direct then the inshore channel; but this outer channel had a bar across it, with a depth over it of only $2\frac{1}{2}$ to 3 fathoms at low-water, about 3 miles wide, as compared with a bar of similar height across the inshore channel, only $\frac{1}{3}$ mile wide. The depth in the navigable channel below Mud Point fell below 3 fathoms for about a mile in the middle of the crossing along Mud Point Channel; but with this exception, though the depth in some parts of this crossing, and in the lower crossing along Lloyd's Channel, was only just 3 fathoms, it did not fall below it, Plate 3, Fig. 13.

The other principal features of the chart in the upper estuary consist of the long Rangafala shoal, a portion of which had developed into a sandbank drying at low-water, another adjacent long shoal with less than 2 fathoms of water over it, extending from a sandbank opposite Rangafala down to opposite Silver Tree, and an island in mid-estuary opposite Balari, with a long sandbank stretching from it down-stream to opposite Haldia, Plate 9, Fig. 1. In the lower estuary, a large sandbank extended down from Mud Point; a large island had recently been formed just below this sandbank, nearly in mid-estuary; another sandbank lower down occupied approximately the site of the present Bedford Sand; and a long sandbank stretched below the outlet of the estuary, with its upper end in the position of the present Lower Long Sand.

Chart of the Húgli Estuary of 1854.—Bedford's chart of 1854 was evidently prepared with less care and detail, as regards the outlines of the islands and sandbanks, than Lloyd's chart of 1836, and, therefore, it is not possible, in this respect, to compare it with other charts of the estuary; and, accordingly, only

the shore-lines of this chart have been put in brown over the reduced chart of 1894-5, Plate 10. The navigable channel, however, is well defined ; and an ample number of soundings are given.

At this period, owing to the extension of Rangafala shoal, a small portion of which had grown into an island, the narrow Inner Rangafala Channel along the eastern shore had become shoal at its upper end ; and the Outer Rangafala Channel, passing between the western side of the Rangafala shoal and the long sandbank in mid-estuary, had become the navigable channel. This channel turned towards the eastern shore opposite Silver Tree Obelisk, and running close to Mud Point, it proceeded across the estuary by a more southerly and diagonal Mud Point Channel, approaching the western shore between Khijiri Point and Kaukhali. Then curving round as in the two previous surveys, the navigable channel passed again diagonally across the estuary by a channel still called Lloyd's Channel, but over $1\frac{1}{2}$ miles to the south-west of the Lloyd's Channel of 1836, and over four miles to the south-west of the Minto Channel of 1814, leading into Saugor Roads, through which it reached the Eastern Channel, Plate 9, Fig. 2. The deep channel from Saugor Roads was rather further from Middleton Point than in the preceding surveys, owing to the growth of a spit westwards from Middleton shoal to the south of Saugor Island.

The navigable Outer Rangafala Channel was shoal towards its lower end as in the previous survey, having two bars across it, with depths over them of from $2\frac{1}{2}$ to 3 fathoms at low-water, opposite Middle Point and Silver Tree respectively, with a total width of about $3\frac{1}{3}$ miles ; and its general depth elsewhere was about $3\frac{1}{2}$ fathoms, increasing to over 4 fathoms in places on approaching Mud Point. The channel from Mud Point, in shifting to a more southerly direction, and therefore more in accordance with the run of the tide, had deepened to between $3\frac{3}{4}$ and $5\frac{3}{4}$ fathoms throughout ; whilst Lloyd's channel, in its altered position, had become narrow and shoaler, with a bar across it having depths of between $1\frac{3}{4}$ and 3 fathoms over it, and a width of $3\frac{2}{3}$ miles, Plate 3, Fig. 13.

The navigable channel, accordingly, in 1854 was more central in the upper part, and more southerly and somewhat less circuitous through the lower estuary, than in 1814 and 1836, Plate 9, Fig 2. Owing to the adoption of the Outer Rangafala Channel for navigation, the upper shoal of the inner channel was avoided, but the lower shoal of the outer channel had to be crossed ; and therefore the upper portion of this channel was deeper, and the lower portion shoaler, than the corresponding channels in the previous charts, Plate 3, Fig. 13. The Mud Point Channel in 1854, though differing in position from the channel of 1813-14, was somewhat similar to it in average depth, and deeper throughout than the channel of 1836. Except for the very deep hollow produced by the scour resulting from the channel of 1836 being directed against Khijiri Point, the three channels of 1813-14, 1836, and 1854, were very similar in average depth in curving round from Mud Point Channel to the lower crossing, along the western side of the estuary ; but from thence, the Minto Channel and the two Lloyd's Channels differed considerably in depth as well as in position,

becoming shallower as they travelled further south and consequently entered the deep hollow of Saugor Roads at a lower point.

Chart of the Húgli Estuary of 1864.—The incomplete chart of March 1864, forming one of the plans illustrating Mr. Leonard's report of 1865,* shows the Inner Rangafala Channel shoal at its upper end, and the Outer Rangafala Channel buoyed as the navigable channel, following approximately the same course as this channel did in 1854, down to about opposite Middle Point, from whence it maintained a more central direction further away from Silver Tree and Mud Point, Plate 9, Fig. 2. After passing Mud Point, it followed an almost southerly course through the Dredge Channel and Bedford Channel into Saugor Roads, as the Mud Point Channel had shoaled considerably and Lloyd's Channel was nearly silted up. The navigable channel, indeed, of 1864 very nearly coincided with the secondary channel shown on the chart of 1768-70.

The Outer Rangafala Channel which was fairly wide and deep from Kantabaria to below Kulpi, became narrower and shallow a little above Rangafala, the depth falling to $2\frac{1}{4}$ fathoms at low-water opposite the island. Above Silver Tree to below Mud Point, the depth of the channel at low-water was for nearly the whole length only between 2 and 3 fathoms, and in two places it was reduced to $1\frac{1}{4}$ fathoms, but deepened again for a little distance south of Mud Point to between 3 and 5 fathoms. In the Dredge Channel, however, from opposite Khijiri to below the South Bluff, the depth fell below 3 fathoms for a considerable portion of its length. Through the Bedford Channel and Saugor Roads, there was a good depth, extending down to nearly $3\frac{1}{2}$ miles below Middleton Point; but alongside the lower part of Middleton Sand and through the Gasper Channel, the central depth ranged almost wholly between 3 and $3\frac{1}{2}$ fathoms.

The navigable channel, accordingly, in 1864 followed a course below Middle Point entirely different from the channel of 1854; but though much more direct, it appears to have been on the whole a decidedly shoaler channel than the channel of 1854.

Chart of the Húgli Estuary of 1867-82.—The chart of the Húgli from Calcutta to Saugor Point, compiled from surveys made by the river surveyors between 1867 and 1882, and published by the Admiralty in 1882, though not purporting to give a chart of the river at any definite period, probably represents a state of the estuary approximating to its condition in 1881; for the navigable channel on this chart bears a much closer resemblance to the next chart of 1883-4, than to the preceding chart of 1864.

In the chart of 1867-82, the two ends of the Inner Rangafala Channel are shown to have shoaled so much that the main remnant of this channel consisted of a deep, narrow hollow close to the eastern shore, almost all along the back of Rangafala Island which had increased considerably in size since 1854. The Outer Rangafala Channel, which at this period had become the only Rangafala Channel, had shifted below Kulpi to a more westerly position than it occupied in 1864, being bounded on the eastern side by the shoal extending from

* "Report on the River Hooghly," by Hugh Leonard, 1865, Plan No. 4.

Rangafala Sand which had grown up to the west of Rangafala Island, and on the western side by the shoal projecting from Haldia Sand. Though the chart shows a depth of 3 fathoms and upwards right through this channel, from Kulpi Anchorage to the upper end of the Jellingham Channel below Haldia Sand, the channel was somewhat tortuous, and became narrow at its lower end. Judging, moreover, by the positions of the buoys on the chart, it appears that even at that period the shifting Outer Rangafala Channel had been abandoned by large vessels in favour of the comparatively stable Balari and Haldia channels, situated between the Haldia shoal and the western shore; although for about 7 miles below Kulpi Anchorage, the Balari Channel had a depth of only between 14 and 18 feet at low-water, and the Haldia Channel had a bar of similar height at its lower end where it curved round, below Haldia Sand, to join the Jellingham Channel, about a mile in width. The Jellingham Channel and Dredge and Auckland Channel, running straight down the estuary nearer to the western shore than to Saugor Island, had a bar between them with a minimum depth over it of 12 feet at low water, and a maximum width of $\frac{3}{4}$ mile. Below this bar, however, along the south-westerly Dredge and Auckland Channel, through the Eden Channel tending southwards towards Middleton Point, past Saugor Roads, and down the Gasper Channel, the chart shows a good, wide channel with depths of between 3 and 5 fathoms throughout.

The westerly position of the channel in the upper estuary, and the somewhat westerly central channel in the upper portion of the lower estuary, shown on the chart of 1867-82, indicated a considerable change from the central course above, and more easterly course below, followed by the main navigable channel in 1864. The change in position of the navigable channel through the lower estuary was accompanied by an alteration in the Bedford Channel and its shoaling up at its upper end, and a complete shift of the Dredge Channel to the west; and it appears to have approximately coincided with the transference of the channel in the upper estuary from the eastern to the western side. A shallow channel along the western shore past Balari and Haldia, is shown on the chart of 1813-14, which had become deeper by 1836, when the Inner Rangafala Channel had been narrowed, the Outer Rangafala Channel had shifted further from the western shore, and the Rangafala sands and shoals had extended considerably. When in 1864 the Inner Rangafala Channel had begun to shoal up at both ends, and the Outer Rangafala Channel had assumed a much more central position, the main channel in the lower estuary had changed its course; and instead of passing in front of the entrance to Channel Creek, and being deflected across the estuary by Mud Point, it proceeded in a more direct southerly line, resembling the secondary channel shown on the chart of 1768-70 when there was a good central Outer, as well as a good Inner Rangafala Channel, Plate 9, Fig. 2. At length in the chart of 1867-82, when the Inner Rangafala Channel had been practically closed, and the western inshore channel had opened out, the channel through the lower estuary, which appears to have been in a state of transition in 1864 in accordance with the channel in the upper estuary, had settled down into a position which, with comparatively moderate changes, it has maintained up to the present time.

*Charts of the Húgli Estuary from 1883-4 to 1895-6.**—Whereas in all the charts up to 1864, two Rangafala Channels are shown, separated by sands and shoals, so in all the charts from 1867-82 to the present time there are invariably a Rangafala Channel in mid-estuary extending from Kulpi Anchorage to the Jellingham Channel, and a western inshore channel, known as the Balari and Haldia Channels, separated from the Rangafala Channel by Haldia Island and its encircling sands and shoals, Plates 9, 10, and 11. The Haldia Channel, following the coast-line, begins to turn to the south on approaching the mouth of the Haldia River, and curving round in passing the mouth, it proceeds due south into the Jellingham Channel. The Jellingham and Dredge Channels maintain a tolerably straight south-westerly course to the Eden Channel which, bending to the south on approaching the heads of the Mizen and Upper Long sands, passes between the Bedford and Upper Long Sands into Saugor Roads. The Balari and Haldia Channels have maintained a very uniform position during the last twelve years, making allowance for the erosion of the shore which has taken place between Balari Tower and Haldia Point; but the central Rangafala Channel has shifted its course considerably from year to year during the same period, the centre line of its navigable channel having ranged over a maximum width of rather more than 1½ miles opposite Middle Point. The Jellingham and Dredge Channels shift somewhat to the north-west or south-east from year to year; but the maximum divergence of the lines of the central navigable channel has been comprised within a width of about ¾ mile in the last twelve years; and the actual variation between the lines of 1883-4 and 1895-6 is remarkably small, considering that these Channels pass almost down the middle of a wide sandy estuary with constantly changing sandbanks on either side, and can only be accounted for by the good position assumed by these channels in a line with the general direction of the flood and ebb currents flowing up and down the estuary. The Eden Channel passing somewhat diagonally across the centre of the estuary, is naturally more variable, the extreme limits of the changes in the position of the centre line of its navigable channel since 1884 being slightly more than a mile apart. The direction of the navigable channel through Saugor Roads and along the Gasper Channel has remained fairly uniform during the last twelve years.

The bars across the navigable channel, or the shoals separating the 3-fathom contours, change greatly in width from year to year, and in most cases more or less in position. Shoals always exist along the upper part of the Balari Channel, the lower end of the Haldia Channel, near the junction of the Jellingham and Dredge Channels, all along the Eden Channel, and especially at its lower extremity, and alongside Middleton Sand below Saugor Roads; and though these several shoals have within the last twelve years had from time to time more than 3 fathoms of water over them for considerable periods, they readily develop into bars under unfavourable conditions, reducing the depth in the channel to less than 3 fathoms at the lowest low-water. The Eden and

* Eight charts of the estuary have been suppiled me relating to this period; but the two earliest charts of 1883-4 and 1887 terminate opposite Saugor Lighthouse and are incomplete on the western side near the outlet, and therefore were not suitable for reproduction as reduced charts to illustrate this report.

Middleton bars are of comparatively recent growth, for a clear channel with a minimum depth of 20 feet was shown over these shoals in the chart of 1867-82; but a narrow bar appeared at the upper end of the Eden Channel in the chart of 1883-4 ; whilst the extension of the shoal from Middleton Sand right across the channel to the Long Sands, so as to form a continuous bar, did not occur till 1890, though Lower Saugor Roads had been deteriorating for some years previously, and indications of the formation of a bar were reported by Captain Petley in 1887.

In the chart of 1883-4, the Balari bar was $5\frac{2}{3}$ miles wide with a minimum depth of 14 feet at the lowest low-water, as compared with 7 miles and a minimum depth of 14 feet in the chart of 1867-82. The Haldia bar was $1\frac{2}{5}$ miles wide with a minimum depth of 15 feet, in place of about a mile in width and 14 feet depth shown on the chart of 1867-82. The Eden bar, which had developed since the chart of 1867-82, was only $\frac{1}{5}$ mile across with a minimum depth of 16 feet, and was situated at the junction of the Eden Channel with the Auckland Channel.

In the chart of 1887, the Balari bar had the same width and minimum depth as in the previous chart. There was no bar across the Haldia Channel at the time of the survey ; but towards the close of the preceding freshets, there appears to have been a bar with a minimum available depth of 16 feet. The Eden bar had travelled rather lower down, and had increased to $2\frac{5}{6}$ miles in width with a minimum depth of 14 feet.

In the chart of the following year, 1888, the Balari bar had increased to $6\frac{1}{4}$ miles in width, and had shoaled to a minimum depth of 13 feet ; but the Haldia Channel was open at the time of the survey in the spring, Plate 9, Fig. 1. The Eden bar had again moved further down ; but though it had decreased in width to about $1\frac{1}{2}$ miles at its narrowest part, its width along the centre of the buoyed channel was $4\frac{1}{4}$ miles, and its minimum depth was 8 feet.

In the following chart of 1889-90, an unusually favourable condition of the navigable channel through the estuary was indicated ; for except a bar across the Balari Channel opposite Balari Tower, about a mile in width, and a minimum depth over it of 15 feet, the 3-fathom channel was continuous between Kulpi Anchorage and the Gasper Channel. The Balari and Haldia channels were, indeed, narrow as usual ; there was a patch of shoal with only 3 fathoms over it at the lowest low-water, in mid-channel, at the lower end of the Jellingham Channel ; a similar patch existed in the narrow and irregular Eden Channel; and the upper end of the Gasper Channel had been reduced in minimum width, by the extension of the spit from the Middleton Sand, from nearly a mile in 1888, to under $\frac{2}{3}$ mile ; but, on the whole, it was a more open channel at this period than shown in any of the previous charts referred to.

The chart made three years later, of 1892-3, showed a considerable change in the condition of the channel through the estuary; for though the Balari bar was very similar in position, and only slightly wider and with 1 foot less minimum depth than in the chart of 1889-90, and the Haldia bar which had re-appeared

had a width of only $\frac{1}{5}$ mile and 16 feet minimum depth, the Jellingham-Dredge bar, last indicated on the chart of 1867-82, had formed again, the Eden bar had become much wider, and there was in addition a Middleton bar. The Jellingham-Dredge bar had a width of rather under a mile, and a minimum depth over it of 11 feet ; the Eden bar was $4\frac{5}{6}$ miles wide, with 14 feet depth ; and the Middleton bar was 3 miles wide, with a similar minimum depth, Plate 11, Fig. 2.

The chart of the following year, 1893-4, shows the Balari Channel free from any bar ; but the Haldia bar had widened to $\frac{9}{10}$ mile, and shoaled to a minimum depth of 11 feet. The Jellingham-Dredge and Eden bars had both travelled downwards ; and they had widths of $\frac{5}{6}$ mile and $3\frac{4}{5}$ miles, and minima depths of 12 feet and 14 feet respectively; whilst the Middleton bar had a width of $2\frac{1}{10}$ miles and a minimum depth over it of 15 feet.

The next year's chart, of 1894-95, indicates the re-appearance of the Balari bar at the head of the channel, $1\frac{3}{5}$ miles in width, and having a minimum depth over it of 12 feet; whilst the Haldia bar had further widened to $1\frac{1}{4}$ miles, but had increased in minimum depth to 12 feet, Plate 10. The Jellingham-Dredge bar had travelled further down, and had been narrowed to $\frac{1}{4}$ mile, but the minimum depth over it had been reduced to 10 feet ; whilst the Eden bar had been reduced by erosion at its upper end to a width of $3\frac{1}{5}$ miles, the minimum depth over it remaining at 14 feet. The Middleton bar had grown to nearly $4\frac{1}{2}$ miles in width ; whilst the minimum depth over it continued stationary.

The chart of 1895-6 indicates that the Balari and Haldia bars had become reduced to $\frac{1}{2}$ mile each, and had increased minima depths over them of 14 and 15 feet, respectively; whilst the Jellingham-Dredge bar, whose downward motion had continued, though widened to $\frac{3}{5}$ mile, had improved one foot in minimum depth with 11 feet over it, Plate 11, Figs. 1 and 2. The Eden bar had been reduced by erosion at both ends to a width of $2\frac{1}{4}$ miles, and the Middleton bar to $3\frac{1}{2}$ miles; but whereas the minimum depth over the Eden bar remained at 14 feet, it had been reduced over the Middleton bar from 15 feet to $13\frac{1}{2}$ feet.

The Rangafala Channel exhibited a bar in all the charts under consideration, generally somewhere opposite Haldia Island, though opposite Rangafala Island in the chart of 1893-4, and opposite Balari Tower in the following chart, Plates 9, 10, and 11. The bars in the several charts, with a minimum depth over them of from 13 to 17 feet in the deepest channel, have varied in width from $\frac{3}{10}$ mile in the chart of 1883-4 to 1 mile in 1893-4 ; and in the chart of 1889-90, when the navigable channel was specially good, the Rangafala Channel was unusually obstructed, with three bars having a total width of $1\frac{1}{4}$ miles. There were two bars across the channel in the chart of 1894-5, with a combined width of only $\frac{1}{3}$ mile ; whilst the single bar shown on the chart of 1895-6 had a width of nearly half a mile, Plates 10 and 11.

Length and Position of Bars in the Húgli Estuary at different Periods.— The total length of navigable channel in the estuary having a depth of less than 3 fathoms at the lowest low-water, omitting the exceptional year 1889-90, has

varied from $7\frac{3}{10}$ miles in 1895-6 up to $10\frac{3}{4}$ miles in 1894-5, on the charts under consideration, between 1883-4 and 1895-6 ; and the average length of shoal channel was $8\frac{3}{4}$ miles in the three earliest charts, and $8\frac{1}{2}$ miles in the three latest charts. Accordingly, with the exception of the remarkable opening out of the navigable channel in 1889-90, no material change in the general average length of the bars across the navigable channel through the estuary can be noted ; and the total length of the bars, though $\frac{1}{4}$ mile longer in 1894-5 than in 1888, was slightly less in 1895-6 than in 1883-4. In all the charts, however, from 1892-3, the bars, though less in maximum width than in the charts of 1867-82, 1883-4, 1887, and 1888, have been more numerous, four bars being indicated in the chart of 1893-4, and five in the other three charts. The situation, moreover, of the wide bars has changed in recent years; for whereas in the charts from 1867-82 up to 1888, the bar across the Balari channel always exceeded five miles in width, in the subsequent years the Balari bar did not appear on the chart of 1893-4, and ranged in width between $\frac{1}{2}$ mile and $1\frac{1}{4}$ miles on the other charts. The Eden and Middleton bars have, indeed, now become the widest bars, ranging in width,since 1893, between $2\frac{1}{4}$ and $4\frac{5}{8}$ miles, and $2\frac{1}{10}$ and nearly $4\frac{1}{2}$ miles respectively. An erosion, however, or accretion of two or three feet may make a considerable alteration in the width of these bars between the 3-fathom contours ; and these bars, moreover, undergo seasonal modifications.

The changes which may take place in the course of a few months are exemplified by the red 3-fathom lines inserted alongside the bars on the chart of 1895-6, Plate 11, Fig. 1 ; for the red lines show the limits of the Balari, Haldia, Jellingham-Dredge, and Eden bars at the time of the survey in December-April 1895-6, and the adjacent black fathom lines the state of these several parts of the channel according to the latest river notices received, namely of August for the Balari bar, May for the Haldia bar, and October for the Jellingham-Dredge and Eden bars. Though the detached shoal which existed in front of the head of the Balari Channel in April had disappeared in August last, the extension of a spit threatened to increase the width of the bar. The improvement of the Haldia bar by the tidal scour during the dry season is indicated by a comparison of the black 3-fathom lines of May last with the red 3-fathom lines of an earlier period in the year. The Eden bar, though apparently narrower in October last than when the survey for the chart of the estuary was taken, had become shoaler. The Middleton bar is shown on the chart of 1892-3, and on the three subsequent charts, with a minimum depth over it of from $13\frac{1}{2}$ to 15 feet ; but in the river notice of last May there was a direct passage across it due south of the Upper Middleton buoy with depths over it of 18 to 22 feet at the lowest low-water, as shown by the red 3-fathom lines on the chart of 1895-6, Plate 11, Fig. 1.

Changes in the Outlines of the Húgli Estuary.—The changes in the shore-lines, islands, and sandbanks in the estuary since 1836 are indicated on Plates 9 and 10, by comparing the reduced charts of 1888 and 1894-5 with the red outlines of the charts of 1836 and 1883-4 placed over each of them respectively, and the brown shore-line of the chart of 1854 put on the chart of 1894-5.

A comparison, moreover, of the charts of 1894-5 and of 1895-6, Plates 10 and 11, enable some idea to be formed of the changes which occur in the estuary in the course of a year ; and as the original chart of 1895-6 terminates at the lower end of the Upper Long Sand, an addition has been made to the south on the reduced chart, Plate 11, by aid of the recently issued corrected Admiralty chart of the Sandheads, so as to include the whole of the Middleton bar, the Lower Long Sands, and the northern portion of the main approach channels from the sea. The principal changes in the shore-lines consist of a large erosion all along the southern shore of Saugor Island, averaging about a mile in width, since 1836, Plate 9, a general tendency to accretion along the southern part of the west shore of Saugor Island up to the South Bluff, arrested sometimes by erosion, especially just above Saugor Lighthouse, and then erosion for the most part from a little north of the South Bluff up to Mud Point, particularly at the narrow neck of land near the upper end of Saugor Island, which has been reduced considerably in width even since 1888, and is likely to be soon cut through. Erosion has also taken place all along the eastern shore of Saugor Island, especially at the northern and southern portions, widening Channel Creek ; and the northern shore of Saugor Island has experienced frequent changes from erosion or accretion, occasioned no doubt by changes in the channel at the entrance to Channel Creek. Channel Creek has also been enlarged by the erosion of the shore on its eastern side, up to within about three miles below Harwood's Point ; whilst accretion has occurred both above and below the point, followed by erosion again near the entrance to the creek opposite the northern extremity of Saugor Island. On the western shore of the estuary, erosion has taken place below the mouth of the Rasulpur, and apparently for a long distance down the coast-line beyond, Plate 12, and also for about 3 miles above the mouth in front of Hijili ; but from thence, past Kaukhali to Khijiri Point, there has been little alteration of the shore. From Khijiri, on the contrary, up to the mouth of the Haldia, though the shore appears to have been eroded for a time, subsequently to 1836, by an inshore channel between the land and projecting sandbanks, Plate 9, the shore had begun to advance at the back of Sandia Island in 1883-4 ; in 1894 Sandia Island had become joined to the shore at its northern end ; and in the chart of 1894-5, it is shown incorporated with the shore, Plate 10, which has led to the accretion of the foreshore below it, so that the whole of the shore-line has advanced between the mouth of the Haldia and Khijiri Point. On the eastern side of the upper estuary, the shore has been eroded in the concave bend at the back of Rangafala Island ; and accretion has taken place, and is still progressing, all along the shore from opposite the lower end of Rangafala Island to Silver Tree Obelisk, the maximum advance of the shore having occurred just below Middle Point, Plate 11. Erosion has occurred all along the western shore of the upper estuary, from above the point near Jigerkhali down nearly to Haldia Point, this point itself having been subject to alternate accretion and erosion. On the whole, the erosion of the shores has considerably exceeded the accretion. If, however, the shores of the navigable estuary alone are considered, down merely to its outlet opposite Middleton Point, and if allowance is made for the circumstance that since 1884 the northern part of the western shore of Saugor Island has tended to advance instead of being eroded, owing to the silting up of the inshore channel

below Mud Point, Plate 10, the lengths of shore-line subject to accretion and erosion, respectively, appear to be approximately similar at the present time.

There have been considerable alterations in the islands in the estuary, into which the higher portions of the sandbanks are gradually converted by accretion and vegetation if left undisturbed by the currents or waves for a sufficiently long period. The island in the middle of the upper estuary off Balari, and the large island nearly in mid-estuary off the upper part of Saugor Island below the neck, which are shown on the chart of 1836, Plate 9, Fig. 1, had apparently disappeared in 1854 ; for Rangafala Island is the only island shown on the chart of that year, Plate 10, and this island had not come into existence in 1836. In the chart of 1867-82, Rangafala Island had grown out considerably ; an island had again appeared off Saugor Island, called Mud Point Island, situated on the extensive sandbank stretching down from Mud Point, in the recess near the narrow neck of Saugor Island ; the long Sandia Island had been formed alongside the western shore below the mouth of the Haldia, on a site covered by water at low tide in 1836 and 1854 ; and the small Stiffe Island had grown up on the middle of the Long Sand, which was washed away during a spring tide in July 1884. The chart of 1883-4, showed a slight extension of Rangafala Island, and Sandia Island about in the same condition as in the chart of 1867-82 ; whilst Mud Point Island had been washed away, and had been replaced by two smaller islands on the same bank, but further off from Saugor Island, called Korapara and Gabtola, which appear with somewhat varied outline on all the subsequent charts, Plate 10. The charts of 1886-7 and 1888 show a slight reduction in the length of Rangafala Island, and a little modification in the shape of Sandia Island since the chart of 1883-4 ; but the principal change in this period was the formation of an island with coarse grass on Haldia Sand, which has appeared on the two latest charts as Haldia Island, Plate 9, Fig. 1. The principal changes in the islands of the estuary since 1888, have been the appearance of a second island with coarse grass off Rangafala Island, which has now developed into the Outer Rangafala Island ; the gradual shoaling up of the channel between Sandia Island and the shore, and the junction of the island with the shore, commenced in 1893 and now completed ; and the development of the growth of coarse grass on Haldia Sand into a regular island.

The sandbanks in the estuary in 1836, according to Lloyd's chart, comprised the central sandbank extending down from the island in the upper estuary, two small Rangafala sandbanks, a sandbank stretching down from Mud Point, a sandbank on the present site of the Bedford Sands, and the Long Sand with its northern extremity south of Saugor Island and below the outlet of the estuary, Plate 9, Fig. 1. Comparing the extent of sandbanks dry at low-water, and islands in the estuary in 1836 and in 1888, which can easily be done by reference to Plate 9, it appears that, even allowing for the increase of the estuary by the erosion of the shores, the area occupied by sandbanks and islands within the estuary was greater in 1888 than in 1836. The sandbanks indicated on the chart of 1854 present a considerably greater area than the sandbanks of 1836 ; but the outlines of the sandbanks in the chart of 1854 appear so unreliable that it would be unsafe to draw any conclusions from them. Some of the most

characteristic sandbanks of the recent charts appear for the first time, somewhat in their present form, in the chart of 1867-82, as, for instance, the Outer Rangafala Sand, the Haldia Sand, the Sandia and Gangra Sands, and the Mizen Sand, after the transformation which had taken place in the course of the main channel through the estuary, and which had occasioned the washing away of the central sandbank in the upper estuary shown on the charts of 1836 and 1854. In the chart of 1867-82, the Long Sand which was being cut into at its lower end was still to the south of Middleton Point, but was joined by a shoal to the eastern corner of the Mizen Sand. This shoal, with a maximum depth over it of 7 feet at low-water, was subsequently raised, for the chart of 1883-4 shows the two sandbanks united, forming one large, wide, central sandbank, Plate 10, effectually shutting off the navigable channel from the Western Channel at the lowest low-water. By 1887, however, the western portion of the Mizen Sand had been cut off from the large sandbank by a channel which had cut its way between them, connecting again the Eden Channel with the Western Channel, Plate 9, Fig. 1. By these changes, the Mizen Sand had been reduced to about half the size indicated on the chart of 1867-82, and the Long Sand had acquired a long spit extending northwards nearly to opposite Black's Point, at the expense of the Mizen Sand. The narrowed neck connecting the Upper and Lower Long Sands was gradually cut through; and a clear channel severing the two sands, from 15 to 28 feet deep, is shown on the chart of 1892-3, connecting the Western Channel with Saugor Roads. At the same period, a shallow channel had been formed dividing the Lower Long Sand in two, so that a great change occurred in the Long Sand between the surveys for the charts of 1889-90 and 1892-3, Plates 9 and 10. These channels through the Long Sand appear to have been both formed by the flood tide coming up the Western Channel, for in both cases they were deepest at their lower end, and a shoal was left in front of their upper extremity. The other principal changes in the sandbanks since 1888, are the extension of the shoal below Rangafala Island and a reduction in area of Haldia Sand; a great increase in Lash's Sand off Mud Point, and a growth of the sandbanks on the western side of the Bedford Channel; an enlargement of the shoal extending below Gangra Sand, accompanied, however, with a lowering of the narrow shoal which connected it with Kaukhali Sand; a further splitting up of the Mizen Sand; and the formation of a long very narrow shoal like a spit extending sea-wards from the small Eagle Sand. The sandbanks in the estuary appear to be slightly larger in extent on the chart of 1895-6 than on the chart of 1888, Plates 11 and 9, owing to the growth of Middle Point Flat and Lash's Sand, which more than compensates for the reduction of Haldia Sand; whilst the changes in the sandbanks below Lash's Sand off Mud Point appear approximately to balance one another. On the other hand, the sandbanks in the chart of 1883-4 seem to be distinctly larger in area than in the chart of 1894-5, which differs little in this respect from the chart of 1895-6, this difference in area being mainly due to the great extent of the connected Mizen and Long Sands in the chart of 1883-4.

Causes of the Changes in the Channels of the Upper Húgli Estuary.—The most notable change in the upper estuary is the shifting of the navigable channel

from the eastern shore of the estuary, as shown on the chart of 1836, to the western shore, as shown on the chart of 1867-82, owing to the gradual shoaling up of the Inner Rangafala Channel, and the corresponding deepening of the Balari and Haldia channels. There has always been an Outer Rangafala Channel ; but it also has gradually shifted towards the western side of the estuary, which led first to the washing away of the sandbank in mid-estuary, shown on the charts of 1836 and 1854, and in more recent years to a considerable erosion of the eastern side of Haldia Sand, Plates 9 and 10. As the shoaling up of the Inner Rangafala Channel and the shifting westwards of the Outer Rangafala Channel have not merely produced a corresponding change in the navigable channel through the upper estuary, but led also to quite as great a change in the navigable channel through the lower estuary, it is important to consider whether the changes in the channels of the upper estuary are likely to be permanent, or are merely temporary, as so often occurs in sandy estuaries, and the navigable channel therefore liable to revert more or less to a former course, such as that followed in 1813-14, 1836,or 1854, Plate 9, Fig. 2. In investigating the causes of the westerly movement of the channels in the upper estuary, it must be borne in mind that, though the influence of the freshets on emerging from the narrow neck at Kantabaria into the widening estuary soon becomes much less than in the river above, nevertheless the freshets still have a powerful effect, especially in the more narrow upper estuary, and that the main channel through the estuary is still principally formed by the descending current, though with diminishing force, right down to the outlet. Accordingly, the general position of the channels in the upper estuary is determined by the course in which the descending current is directed in issuing from the narrow neck at Kantabaria; and this depends upon the direction followed by the current in the reach above in relation to the neck. Now, it has been already seen, in comparing the charts of the Húgli between Húgli Point and Kantabaria, that there was an inshore channel between Diamond Sand and the right bank in all the charts up to 1836, and that the chart of 1867-82 showed Diamond Sand for the first time connected with the shore. Moreover, it was noticed that erosion had taken place along the left bank in the concave bend opposite Diamond Sand, and accretion on the right bank alongside Diamond Sand. The main current, accordingly, has been concentrated in the deep channel round the bend between Diamond Harbour and Kantabaria by the closing of the inshore channel, and shifted somewhat eastwards by the erosion of the concave bank, and therefore directed by the increased bend more to the west below the neck, which has been further promoted by the resulting erosion of Jigerkhali Point. This gradual diversion of the main descending current towards the west, away from the Rangafala shore, which appears to be still in progress, has naturally led to the shoaling up of the Inner Rangafala Channel, the extension of the Rangafala Sands, the formation of the Rangafala Islands and the Middle Point Flat, the shifting of the Outer Rangafala Channel westwards, and the opening up of the Balari and Haldia channels. The recent growth also of Lash's Sand, and the permanence of the sands and islands on the east side of the estuary to the south of Mud Point, may be traced to the same cause. Moreover, the formation of Sandia Island and the outlying Gangra Sand, which appeared first on the chart of

1867-82, seems to be due to the changes in the channels in the upper estuary, having led to the maintenance, since 1881 or probably earlier, of the main channel, below Haldia Island, in mid-estuary away from the western shore, towards which it was directed prior to 1864 by the projecting Mud Point.

As the changes in Diamond Sand and the adjacent channel are likely to be permanent, and the erosion of the concave bank and the accretion of the opposite bank appear to be going on at the present time, there is no prospect, under existing conditions, of the main channel again shifting to the eastern side of the upper estuary, and therefore no probability of the main channel through the lower estuary reverting to the general course which it followed from 1814 to 1854. The great reduction, indeed, in the width of the bar across the Balari Channel subsequently to the chart of 1888, is most probably due to the gradually increasing diversion of the main descending current towards the west, having caused a larger volume of water to flow down the Balari Channel in recent years. Moreover, as the causes promoting this westerly diversion are still in operation, it is probable that the recent improvement in the Balari Channel will be maintained, and that the growth of the sandbanks on the eastern side of the estuary will continue.

Causes of the Bars across the Navigable Channel in the Húgli Estuary.— The Rangafala Channel is the main, direct channel of the freshets and the ebb tide through the upper estuary; and the Balari Channel is merely a secondary channel, formed by a branch from the main current guided by the western shore, and scouring a deep channel along the concave bank at the back of Haldia Island. A bar is, therefore, generally formed at the head of the channel, where the variable secondary current branches off from the main current, till on reaching the western shore it is directed between the western shore and the Haldia Sand with its projecting shoal, where it maintains a deep channel along the shore, Plates 9, 10, and 11.

The Haldia bar is formed where the current descending the Haldia Channel emerges from the guidance of the Haldia and Gungra sands, and clashes with the main current flowing direct from the Rangafala Channel into the Jellingham Channel. The minor Haldia Channel current, accordingly, is checked on approaching the main current, and therefore generally forms a bar from about the point where it ceases to be directed by the shoal off Haldia Sand to its junction with the main current, Plates 10 and 11, except when the tail of the shoal of Haldia Sand extends down to the Jellingham Channel, as shown on the charts of 1887, 1888, and 1889-90, Plate 9, leading the Haldia Channel directly and at a more favourable angle into the main channel.

A bar is found in all the charts subsequent to 1867-82 across the Rangafala Channel, as in the earlier charts, which is produced where the rapid, silt-bearing current, after issuing from the narrow neck at Kantabaria, gradually loses velocity and scouring power as it spreads out in flowing down the enlarging estuary encumbered with sandbanks and shoals. The position and extent of the bar varies with the changes in the channel, and the reduction in the strength of the current; but the bar has not been so wide in recent years as shown on the

earlier charts, owing probably to the current having been more concentrated in the channel since the change in its direction and the great extension of the Rangafala Sands. The alterations in the course of the channel, which render it inconvenient for navigation, are the natural result of the irregular flow of a rapid, variable, undirected current through a sandy estuary, especially as owing to the bend at the head of the estuary, the descending current diverges from the direct course of the flood tide.

The shoal which has always been liable to form near the lower end of the Jellingham Channel, and which in 1893 developed into a bar stretching right across the channel, appears to be due to the deposit of sand towards the close of the freshets brought into the channel by the more rapid Rangafala and Haldia currents. The Jellingham Channel is deep for some distance below the confluence of the currents from the Rangafala and Haldia Channels ; but it shoals where the channel widens out opposite Gabtola Island, Plate 10, and more particularly where a portion of the descending current finds an outlet below the Gangra shoal into Kaukhali Roads, and thence to sea by the Western Channel. Accordingly, when there is a continuous shoal, with a maximum depth over it of only one or two fathoms at the lowest low-water, connecting Gangra Sand and Kaukhali Sand, thereby hindering any material diversion of the discharge from the Jellingham Channel into Kaukhali Roads, as was the case in 1883-4, 1887, 1888, and 1889-90, Plate 9, Fig. 1, the current being fairly confined within the channel, scours away the shoals which move as lumps down the channel, like the sand-waves observed travelling down the Mississippi, or prevents the obstruction from extending right across the channel. When, on the contrary, the shoal between Gangra Sand and Kaukhali Sand is low, as shown on the chart of 1867-82, and still more when a clear opening exists between the Gangra and Kaukhali sands, as indicated on the chart of 1894-5, Plate 10, or when an unusual obstruction appears in the channel, such as was rapidly formed by the consolidation of the moving lumps under the shelter of the *Anglia* wreck early in 1893, the current flowing down the Jellingham Channel is partially diverted towards Kaukhali Roads ; and the enfeebled current is no longer able to maintain a deep channel across the shoal. The bar, however, which appears extending across the channel in the chart of 1892-3 and in the subsequent charts has gradually moved further down the channel, Plate 11, Fig. 2 ; and if the shoal connecting the Gangra and Kaukhali sands should form again, of which there appears to be some prospect, as the passage through has shoaled 3 feet since 1894-5 according to the recent chart, it is probable that the augmented current resulting from the checking of the outflow into Kaukhali Roads, would scour away the bar, as evidently happened between the charts of 1867-82 and 1883-4.

The freedom of the Eden Channel from a bar in the chart of 1867-82, contrasting so remarkably with its condition since 1892, appears to have been due to its having been at that period the only convenient channel for the outflow from the Dredge Channel ; for the Mizen Sand was connected by a high shoal with the Long Sand, and the outlet of the Auckland Channel between the Mizen Sand and Kauhali Sand had become shallow. As soon, however, as a passage

had been scoured out between the Mizen Sand and the Long Sand, as shown on the chart of 1887, a bar of considerable length formed across the Eden Channel, on account of the new outlet available for the descending current leading into the Western Channel, and the new passage provided for the flood tide to ascend the estuary, Plate 9, Fig. 1. The Eden Channel improved again when the passage between the Mizen and Long Sands shoaled somewhat, as shown on the chart of 1889-90 ; but it deteriorated again on the opening out of a third outlet to the west of the Mizen Sand, as shown on the chart of 1892-3 and the subsequent charts, Plates 10 and 11. The condition, indeed, of the Eden Channel clearly depends upon the extent to which the currents maintaining it are not diverted from it into the more westerly channels connecting the Dredge Channel with the Western Channel. Since 1892, the Eden Channel has been only one of three channels leading from the Dredge Channel to the sea, but it has hitherto remained the best channel ; for whereas it has shown a minimum depth of 14 feet at the lowest low-water on the four last charts, the passage between the Mizen and Long Sands has not had a continuous 2-fathom channel through it during that period. Moreover, the 2-fathom channel was not continuous along the channel to the west of the Mizen Sand in the chart of 1893-4, and there are signs of a fresh shoaling of this channel in the chart of 1895-6, Plates 10 and 11 ; whereas the Eden Channel has somewhat improved. The opening up of these western channels would be prejudicial to the Eden Channel ; whilst, on the contrary, their shoaling up would be accompanied by an improvement of the Eden Channel. The Eden bar rises gradually as it approaches Saugor Roads, Plate 11, Fig. 2, partly on account of the spreading out of the current on emerging from between the shoals projecting from the Bedford and Upper Long Sands, and partly owing to the main run of the flood tide from the Eastern Channel passing up the direct Bedford Channel at an angle to the course of the Eden Channel, Plate 11, Fig. 1.

The Middleton Bar which gave signs of its formation in 1887, and was actually formed right across the channel in 1890, appears to be mainly due to the opening out of the Western and Long Sand channels. A shoal is, indeed, naturally formed where a silt-bearing current emerges from a comparatively narrow channel into the wide expanse south of Saugor Island, being aided, moreover, by the great erosion of the south shore of the island; but these influences have been in operation for a long time without producing an actual bar with less than 3 fathoms of water over it at the lowest low-water, and therefore do not account for the recent appearance of a bar right across the channel, and of considerable width. The diversion of a portion of the current which formerly flowed down the Eden Channel into Saugor Roads, and thence to the Gasper Channel, would necessarily affect these channels ; and therefore the opening out of a passage between the Mizen Sand and the Long Sand, which occurred between the surveys of 1883-4 and 1887, diverting a portion of the flow from the navigable channel into the Western Channel, was very naturally followed by an extension of the Middleton shoal. Moreover, the Long Sand Channel which was scoured out, through the narrow neck which in 1890 connected the Upper and Lower Long Sands, between the surveys of 1889–90 and 1892–3, has furnished another outlet for the escape

of some of the current flowing through Saugor Roads, away from the channel over the Middleton bar, and another inlet for the flood tide to flow into Saugor Roads from the Western Channel above the Middleton bar. This cross Long Sand Channel, accordingly, connecting Saugor Roads directly with the Western Channel, reduces the scour of the descending current across the Middleton bar, and impedes the influx of the flood tide from the Eastern Channel over the bar, and thus fully accounts for the increased width of the Middleton bar since 1892. The bar, however, between the Long Sand Channel and Saugor Roads is wider on the recent chart, Plate 11, than on the chart of 1894-5, Plate 10; whereas the width of the Middleton bar has been reduced about a mile in the same period. The change, consequently, of the outlet of the navigable channel from the Eastern Channel to the Western Channel, through the new Long Sand Channel, which appeared imminent in 1895, has been checked; and it will be advantageous for navigation if, notwithstanding recent appearances, this change is not effected, and the Long Sand Channel closes up again; for this new course for the navigable channel would be exposed and circuitous; and the direction of the Long Sand Channel, situated diagonally to the estuary, has little prospect of prolonged stability.

Remarks on the Changes in the Húgli Estuary.—The most remarkable feature in the foregoing comparison of the various charts of the estuary to which access has been obtained, is the great stability exhibited by the course of the navigable channel during the last fifteen years or more, as compared with the changes which occurred between 1813-14 and 1836, 1836 and 1854, and more especially in the ten years between 1854 and 1864, and between the charts of 1864 and 1867-82, Plate 9, Fig. 8. The widening of the estuary by erosion, especially along the western shore of Saugor Island, which has naturally been regarded as a possible source of deterioration, from the greater scope thereby afforded for the wanderings of the channel, has certainly had no influence on the course of the navigable channel during the last fifteen years, beyond the slight change which the erosion of the western shore between Balari Tower and Haldia Point has naturally produced in the position of the Balari and Haldia channels. As regards direction, indeed, the general course of the navigable channel since the chart of 1867-82 is clearly superior to any of the earlier channels of the present century, with the exception of the channel of 1864, which, however, was both changeable and shallow; and therefore in this respect there has been an improvement of late years, instead of a deterioration, in the navigable condition of the estuary. The improvement, moreover, is still more marked in the comparative stability of the navigable channel; and the longer this stability is maintained, the more will the growth of sandbanks at the sides, away from the influence of the currents in the channel, tend to perpetuate the permanence of the channel. There are, however, some signs of changes, much the most important of which are the opening out of the direct Western Channels on each side of the Mizen Sand, and the still more recent formation of the Long Sand Channel, threatening to produce a change in the navigable outlet. These changes have already occasioned a shoaling of the Eden Channel, a deterioration in Lower Saugor Roads, and the formation of the Middleton bar,

constituting a very marked deterioration in the lower part of the present estuary channel during the last three or four years, which appears likely to continue so long as these branch channels remain open. The minor changes are the modification in the position of the Balari and Haldia Channels, owing to the erosion of the western shore; and the permanence of the obstruction of the Jellingham-Dredge bar across the channel since 1893, promoting the diversion of a portion of the current away from the navigable channel below, as well as forming an additional impediment to the passage of vessels down the estuary. Some change is likely to occur alongside Saugor Island when the narrow neck below Mud Point is cut through; but the navigable channel is now at such a distance from this place, and the sandbanks have extended so much on the western side of the recess alongside the neck, that it is improbable that the formation of a channel through the neck, and the consequent changes, will have any influence on the navigable channel.

The depth along the navigable channel has necessarily varied considerably in the different parts of the estuary, with the changes in the position of the channel, Plate 3, Figs. 13 and 14, and therefore no general comparison of the longitudinal sections obtained from the several charts can be made; but whilst they indicate fluctuations in depth, there are no indications of a general shoaling of the navigable channel. The best comparison of the channels at different dates, as regards navigability, appears to be the total length of channel in each case, in which the depth was less than 3 fathoms at the lowest low-water. According to this standard of comparison, the navigable channel in 1813-14, with a length of barred channel of $2\frac{1}{2}$ miles, was inferior to the channel of 1836 with a length of only $1\frac{1}{3}$ miles, and superior to the channel of 1854 with a total length of bar of about 7 miles. The datum, however, of the 1836 chart is uncertain; and a very slight lowering of the low-water datum of the soundings in this case would produce a great increase in the length of the bars. It is impossible to obtain the approximate widths of the bars on the rough small-scale chart of 1864; but the channel was evidently more obstructed by bars, and shallower in some places than in 1854. The bars shown on the more recent charts have been already compared; and from their widths it would appear that, with the exception of the channel shown on the chart of 1889-90, the total length of bars along the navigable channel in the charts from 1867-82, up to the present time, approximate to the condition of 1854. The total length, in fact, of 3-fathom channel and upwards during the last fifteen years has been, on the average, somewhat less than in 1854 and much less than indicated on the charts of 1813-14 and 1836, but decidedly greater than in 1864; whilst the navigable channel shown on the chart of 1889-90 had a smaller width of bar of under 3-fathoms than indicated on any previous chart of this century, On the whole, so far as reliance can be placed on the indications of the charts of 1813-14 and 1836, the navigable channel through the estuary appears to have possessed a better depth in the earlier part of this century than since 1854. As regards, however, recent years, the reduced length of 3-fathom channel was mainly due up to 1890 to the width of the Balari bar, and would have disappeared if the measurement had been taken along the Rangafala Channel with its

comparatively narrow bar; and since 1890 it has been due to the great increase of the Eden bar, and the development of the Middleton bar.

Considering the uncertainty as to the correctness of the indications afforded by the two early charts of 1813-14 and 1836, the very bad state of the navigable channel in 1864, and its remarkably good state in 1889-90 which, except for the opening out of the new western channels, might have been still maintained, it cannot be assumed that there has been any general gradual deterioration of the navigable condition of the estuary. Moreover, if the width of the bars across the channel is generally greater now than early in the century, as indicated by a comparison of the charts, this is compensated for by the improved direction, and much greater stability of the navigable channel.

The growth of the islands, sandbanks, and shoals, which appears to have occurred at the sides of the estuary since 1836, cannot be regarded as a deterioration, for it only indicates the progress of the inevitable change which, in any deltaic estuary, tends to convert the upper portion of the estuary into a river confined by banks, and gradually prolongs the lower part of the estuary sea-wards. This process, however, appears to be extremely slow in the Húgli; and at the present time, there are more indications of a restriction of the wanderings of the channel in the upper estuary by accretion on the eastern side, than of an extension of the estuary southwards, owing to the erosion of the southern shore of Saugor Island instead of the advance which might have been expected.

The excellent yearly charts of the whole estuary now being published regularly by the Deputy Conservator, will in time furnish a continuous record extending over a sufficiently long period to enable the nature, extent, and tendency of the changes in the estuary to be determined with much greater precision than is possible from a study of charts, mostly incomplete except as regards the navigable channel, and published at long intervals apart. In order, however, to furnish a complete record of the condition of the estuary each year, it would be well to add to each chart of the estuary a chart of the river between Luff Point and Kantabaria, the changes in which affect the channels at the upper end of the estuary, as was done in the case of the charts of 1892-3 and 1893-4; and instead of terminating the chart of the estuary just below Saugor Island, as in the chart of 1895-6, it is very important that the yearly charts should be continued down below the Middleton bar to deep water in the Gasper Channel, as was done in the three preceding charts. This portion of the estuary is, indeed, of special interest at the present time, for the lower end of the channel, from the Eden Channel down to the Gasper Channel, appears to be most subject to deterioration under existing conditions; and changes in the Long Sand Channel (which is omitted from the estuary chart of 1895-6), as well as in the direct western channels, are likely to determine in the near future whether the present navigable outlet can be retained, or whether it will be necessary to resort to the Western Channel. Such a change has occurred in the past, for it appears from the mention in the earliest chart of the estuary of the Eastern Channel as "the old passage out," that the outlet channel must

have changed from the east to the west towards the end of the seventeenth century, or at the beginning of the eighteenth century. A change of this kind, however, is, for a time at least, unfavourable for navigation; for a period of transition generally implies the existence of two channels, which the divided currents are unable to maintain at the normal depth.

CHANGES IN THE SEA-FACE OF THE GANGES DELTA.

A chart has been prepared of the sea-face of the Ganges delta, in which the sandbanks and fathom lines obtained from Lloyd's chart of 1837-40 are shown in red, and those taken from the chart of 1877-87 are drawn in black,* Plate 12, Fig. 1, with the object of tracing the changes which have taken place during that period along the front of the delta, and of ascertaining whether these changes are likely to have any prejudicial effect on the navigable condition of the approaches to the Húgli.

Indications of Charts of the Ganges Delta of 1837-40 and 1877-87.—The plan compiled from the charts of the sea-face of the Ganges delta shows that the greatest advance of the foreshore in front of the delta has taken place opposite the four mouths at the extreme east of the delta, situated in a large recess where the foreshore is much flatter than elsewhere, and the 10-fathom line is 75 to 80 miles distant from the coast. Several very extensive sandbanks have been formed at this part of the delta in the interval between the two surveys, and there has been a general progression sea-wards of the 3-fathom line, amounting to as much as 10 miles at the extremities of some projecting spits; but the greatest advance has occurred in the 5-fathom-line, which shows a maximum progression of about 17 miles. These mouths, however, are the furthest removed from the Húgli at the opposite extremity of the delta; and the sea bottom in front of them is to some extent cut off from the western foreshore of the delta by the deep hollow which runs up so far towards the land, near the centre of the delta, that the 100-fathom line comes within 20 miles of the shore; and therefore there is no prospect of the rapid advance of the eastern portion of the delta affecting the approaches to the Húgli. The great influence exercised by this deep hollow in which soundings of 240 to 595 fathoms have been obtained, is manifested by the convergence towards it of all the channels, submarine spits, and sandheads, from one end of the sea-face of the delta to the other, Plate 12, Fig. 1.

On proceeding from the eastern mouths towards the west, where the foreshore becomes steeper on approaching the deep hollow, the chief advance has occurred in the 3-fathom line, which continues westward of the hollow, with a gradual decrease in the advance, and an occasional small progression of the 5-fathom and 10-fathom lines, up to the Sandheads extending in front of the Húgli estuary. Accordingly, the rate of advance of the foreshore appears to diminish from east to west along the delta, notwithstanding the flattening of the slope of the foreshore as the distance west of the deep hollow is increased. In this

* The chart of 1877-87 was the most recent chart till the issue this autumn of a corrected copy of this chart containing alterations in the Sandheads, obtained from a survey made this year by Captain Petley shown on Plate 12, Fig. 3.

respect the Húgli estuary seems to be very favourably situated; though the 10-fathom line is about 40 miles to the south of Saugor Island.

Changes in the Sea Bottom in front of the Húgli Estuary.—Three charts of the lines of soundings to the south of the Húgli estuary, prepared by Captain Petley from Ritchie's chart of 1768-70, Lloyd's chart of 1837-40, and his own survey of the Sandheads this year, enable some idea to be formed of the advance which has taken place at the Sandheads between the periods of these charts. For the sake of comparison, the lines of the chart of 1768-70 have been inserted in red on the chart of 1837-40, in Plate 12, Fig. 2, and the lines of the chart of 1837-40 in red on the chart of 1896, in Fig. 3, showing at a glance the changes in the lines in the two intervals. A comparison of the lines of the charts of 1768-70 and 1837-40, Plate 12, Fig. 2, indicates that in the interval between the charts, one sandbank on the site of the present Lower Long Sands had taken the place of three smaller sandbanks, Saugor Sand had begun to form to the south-east of Saugor Island, and the Sandheads appear to have shifted somewhat westwards; and whilst there was a considerable advance of the 5-fathom and 10-fathom lines to the east of the Eastern Channel, and some advance of the 10-fathom line in front of the Eastern and Western Channels, the fathom lines showed a tendency to recede to the west of the Western Channel. In the interval between the charts of 1837-40 and 1896, a considerable increase has occurred in the Saugor and Long Sands; but whilst there has been a moderate advance generally of the 3-fathom and 5-fathom lines, and a considerable advance of the 10-fathom line to the east of the Eastern Channel, there has been practically no advance of the 10-fathom line in front of the Eastern and Western Channels, and the Eastern Channel has become wider towards its outlet, Plate 12, Fig. 3.

The 5-fathom contour of the Eastern Channel extends quite as far up towards the Húgli estuary at the present time as in the charts of 1837-40 and 1768-70; but it has moved eastwards at its upper end during both periods, approaching now near the western side of Saugor Sand. The 3-fathom contour of the Eastern Channel has extended considerably northwards, approaching much nearer to the southern shore of Saugor Island now, than in the chart of 1837-40, indicating a large erosion of the foreshore above the 5-fathom depth, and accounting for the continued erosion of the southern shore of Saugor Island. The 5-fathom contour of the Western Channel, which receded from the estuary between 1768-70 and 1837-40, has again extended nearer the estuary since 1837-40, reaching the south-western side of the Lower Long Sands, which may account for the recent opening out of the western channels into the estuary, as the 5-fathom contour of the Western channel approaches nearer to the estuary, and is much more central, than the 5-fathom contour of the Eastern Channel with its eastward tendency. The Eastern Channel, however, still provides the most direct course for the currents to the deep hollow.

Remarks on the Influences of the Changes in the Delta on the Húgli Estuary.—It has been seen that the outlet of the Húgli is most favourably situated where the advance of the delta is comparatively slow. The advance of the

10-fathom line in front of the outlet channels, which occurred between 1768-70 and 1837-40, has not continued since, except to the east of these channels ; and the Eastern Channel, as gauged by its 5-fathom contour, extends as far up towards the estuary as it did 126 years ago, and the Western Channel seems to have been returning to the northern limit which it occupied in the eighteenth century. Moreover, the shallower portion at the head of the Eastern Channel, between the 5 and 3-fathom depths, has progressed considerably northwards towards Saugor Island, Plate 9, Fig. 1, and Plate 12, Fig. 3. Accordingly, it is evident that the recent deterioration between the Gasper Channel and Saugor Roads, by the formation of the Middleton bar, has not been caused by any retrogression of the Eastern Channel away from the Húgli estuary by the accumulation of deposit brought down by the river, but that the actual encroachment of the Eastern Channel on the foreshore to the south of Saugor Island has been more than counteracted by the northerly extension of the Western Channel, opening out the Western and Long Sand Channels. In fact, the recent deterioration of the navigable channel, by the shoaling of the Eden Channel and the appearance of the Middleton bar, appears to be wholly due to the greater improvement of the Western Channel, by a greater extension northwards towards the Húgli estuary, in a more central direction, than of the Eastern Channel with its easterly trend. The northern portions of the Eastern and Western Channels constitute at present the most important features in relation to the navigation of the Húgli estuary ; for, if the Western Channel continues to improve, it must before long become the navigable outlet ; whereas, if this channel has already attained its greatest northern extension, and has again begun to recede, as appears to be the case from a comparison of the northern limit of its 5-fathom contour on the charts of 1888 and 1896, Plates 9 and 11, and this retrogression should continue, the deterioration of the Western and Long Sand Channels, indicated on the chart of 1896, will progress, and the Eden Channel and the channel between Saugor Roads and the Gasper Channel will correspondingly improve.

The sand and mud brought down by the Húgli and its tributaries during the freshets, which were regarded by Mr. Leonard and others as an inevitable source of deterioration to the navigable condition of the Húgli, and which appear to have produced an advance of the 10-fathom line sea-wards in front of the outlet channels between 1768–70 and 1837–40, have been unable to arrest the improvement, in other respects, of the Eastern and Western Channels since the latter date, or to carry on the advance of the foreshore in front of them. The sand annually brought into the Húgli, and eroded from its bed during the height of the freshets (being replaced by fresh deposit towards their close), increases the sandbanks in the river in proportion as the width is augmented, deposits at the sides of the estuary beyond the main run of the currents, and tends to prolong the estuary by the extension of Saugor and Long Sands with their projecting shoals, and the Sandheads beyond, more especially to the east of the Eastern Channel ; but, except under unfavourable conditions, it does not appear to prejudice the normal, navigable condition of the river, estuary, and approaches. The mud forming the other part of the alluvium brought down, can only settle in sheltered recesses or slack-water ; and it is probably, to a very great extent, carried out by

the issuing current, with the lighter particles of sand towards the deep hollow, right away from the approaches to the Húgli. Most of the sand brought down by the Húgli appears to deposit to the east of the Eastern Channel ; and this place will naturally continue to be the principal zone of deposit, owing to the easterly set of the issuing current, so long as this channel remains the chief outlet for the discharge of the freshets from the river. The gradual extension of the tails of the Sandheads sea-wards will, no doubt, in process of time, be accompanied by a raising of the sands at their upper ends, eventually producing a prolongation of the estuary sea-wards ; whilst, at the same time, the gradual accretion on the eastern side of the upper part of the estuary will also eventually prolong the river portion of the Húgli below Kantabaria. The advance of the Sandheads in front of the Húgli estuary is almost wholly confined to the Sandhead on the east side of the Eastern Channel ; and, though the advance of the 5-fathom line of this particular Sandhead appears to have averaged about 8 miles between 1768–70 and 1837–40, if the early chart can be relied on, or a rate of advance of a mile in $8\frac{3}{4}$ years, the average advance between 1837–40 and 1896 was only about 4 miles, equivalent to a rate of advance of a mile in 14 years, Plate 12, Figs. 2 and 3. The rate of advance, however, of the 3-fathom line of this Sandhead was nothing in the first period, and about a mile in 22 years during the second period. The advance, accordingly, of the Eastern Sandhead is, on the whole, somewhat slow, and the advance of the other Sandheads to the west of it quite insignificant ; whilst the prolongation of the estuary sea-wards is almost imperceptible, the only indications of it, after the lapse of 126 years, being the extension of Saugor and Long Sands with their shoals below. Moreover, in spite of the progress sea-wards of the tail of the Eastern Sandhead, and the slight advance of the Sandhead between the Eastern and Western Channels, these channels have extended northwards towards the Húgli estuary during the last 56 years, indicating that the advance of the Sandheads exhibits no tendency to produce a deterioration in the approaches to the Húgli. The extension of the Sandheads, indeed, like the accretion at the sides of the estuary above, serves to direct and concentrate the discharge from the river ; and this influence would counteract any tendency to shoaling at the outlets, which might arise if an advance of the fathom lines sea-wards in front of the outlet channels should reduce the slope of the issuing current.

III. Improvement of the River Húgli.

The foregoing comparison of the various charts and surveys of the River Húgli shows that the Húgli is a fairly stable river, undergoing, indeed, considerable fluctuations in depth at some places, according to the seasons and the volume of the freshets, but free from any general deterioration in its condition between Calcutta and the sea.

General Condition of the River Húgli.—Between Calcutta and the estuary, the Húgli exhibits the ordinary features of a winding tidal river, having deep channels along the concave banks in the bends, shoals at the crossings between the bends, and sandbanks projecting from the convex banks below the points, which are cut into at their tails by the flood tide, and increase in extent with any enlargement of the river. Although this portion of the river appears

to be gradually increasing in width along most of its length, an adequate depth has been maintained in the stable navigable channel, except at the Moyapur crossing and the James and Mary reach, which are the only places where the shoals rise above the 3-fathom depth at the lowest low-water, and deterioration is in progress in the shifting navigable channel across these shoals.

The navigable channel through the wide estuary, which formerly shifted considerably from time to time, has remained remarkably uniform in direction during the last fifteen years, presenting a striking contrast in this respect to the changes constantly going on in the channels through other sandy estuaries , such, for instance, as the Seine, where the navigable channel was on the north side near Havre in 1883, and ran close to Honfleur on the south side in 1889. The total length of the shoals in the estuary channel of the Húgli seems to have been greater in some recent years than shown on two of the early charts ; but this may be due to periodical fluctuations in depth, as there are no signs of a general deterioration in the channel. The shoals, moreover, are not permanent obstructions ; for the principal shoal in the upper estuary has, of late years, decreased greatly in width ; whilst the recent extension of shoals near the outlet of the estuary appears to be due to the western side channels opened out by the recent progression northwards of the Western Channel.

The outlet channels passing between the Sandheads to the sea do not appear to have deteriorated at all during the last 56 years, according to the comparison of the charts given above.

The Húgli, accordingly, with the exception of the well-known obstacles to navigation at Moyapur and in the James and Mary reach, affords no indication, either in its river portion, its estuary, or its outlets, of progressive deterioration rendering it necessary to contemplate its abandonment, as the navigable outlet for the trade of Calcutta, at some future period. Unless some unexpected change of the course of the Ganges should occur, so as to deprive the Nadia rivers of their annual supply, and thereby materially reduce the discharge of the Húgli, or unless the occurrence of some seismic or cyclonic disturbance should alter the existing conditions unfavourably, there is every prospect that, provided the two obstructions in the river can be removed, and some improvements effected in the estuary, the Húgli will provide in the future a considerably better waterway between Calcutta and the sea than it has done in the past. The natural capabilities of the Húgli for navigation are evidenced by the cricumstance that, in spite of some proverbial dangers in its channel, and in the absence of any improvement works, beyond some trial spurs at Moyapur and some temporary raking of the shoals in the upper part of the estuary, carried out by Mr. Leonard about thirty years ago, the river has, hitherto, provided a moderately accessible waterway up to Calcutta for vessels of larger draught than in former days. This has, undoubtedly, been due to the introduction of steamers and tugs for navigating the river in place of sailing vessels ; the greatly increased number of buoys and crossing marks for indicating the deepest channel ; the improved and more frequent surveys of the river and yearly charts of the estuary ; and the numerous river notices issued to

pilots. These advantages, however, appear now to have been carried almost to their fullest extent; and further facilities for navigation must be sought in river works.

Improvements required in the River Húgli.—The gradually increased draught of vessels, the extending demands of sea-going trade, and the keen and growing competition of ports, have rendered very extensive improvement works necessary for many rivers leading to seaports, in order that the trade of the ports on their banks might be maintained and extended by the provision of a safe and adequately deep waterway to them. Few ports, indeed, have been able to rest content up to the present time, like Calcutta, with the many valuable improved indications of the navigable channel, such as the experienced river surveyors of the Húgli have devised ; and the Húgli can hardly be regarded, at all times, as an adequately safe and accessible waterway for the trade of Bengal.

Fortunately, the Húgli does not appear to be so subject to deterioration, or to present such peculiar conditions as to render it incapable of improvement, in accordance with the principles which have, within the last quarter of a century, been applied with such conspicuous success to rivers less favourably endowed with natural capabilities for navigation. Rivers, with a much greater fall than the Húgli, with more rapid currents, with a less stable bed, with a more irregular flow, bringing down large quantities of alluvium and devoid of the advantages of a tidal flow, have been improved for navigation, in spite of some of these disadvantages ; and the Húgli is better adapted for improvement than some rivers upon which successful works have been carried out.

The navigable depth to be obtained by works must depend in a large measure upon the natural condition of the river, and the extent or probable growth of its traffic ; for a depth which might be attainable in a comparatively small river, or in a large river under favourable conditions, in view of a very large traffic, might involve too great a cost in the case of a large river with a rather small natural depth, and a moderate traffic. The Húgli, at the present time, possesses an almost continuous 3-fathom channel between Calcutta and the estuary, and down, in fact, to the Balari bar, having only two breaks in it, namely, at the Moyapur crossing and in the James and Mary reach, either at the lower end of the Eastern Gut or at Ninan, Plates 2 and 4. If, therefore, the bars at these two reaches could be removed, there would be a continuous 3-fathom channel between Calcutta and the Balari bar at the lowest low-water, giving an available minimum depth of about 28 feet at high water of low neaps, and about 34 feet at high water of ordinary springs. If, moreover, these two reaches were improved, the progressive deterioration at these places, which threatens at present increasingly to impede the navigation, would be arrested. Improvement works, accordingly, at these two places causing the lowering of the bars, would constitute a notable amelioration of the navigable condition of the river, and remove the principal obstacles, in the opinion of the pilots, to the satisfactory navigation of vessels proceeding from Calcutta to the sea. Though a 5-fathom channel exists along most of the distance between Calcutta and Balari, a continuous channel, more than two or three feet deeper than the

3-fathom channel, would necessitate some improvement of the Royapur crossing, Plate 5, Fig. 27.

The formation and maintenance of a 3-fathom channel across all the bars in the navigable channel through the estuary would, under existing conditions, be, in most cases, too difficult and costly a work to be reasonably undertaken; and the work in the estuary will probably have to be restricted to the opening out of certain portions of the channel, which the scour of the currents, though unable to effect, may be able to maintain, and to the lowering of the crests of the bars, which, occasionally rising to a higher level than usual for a short distance, unduly restrict the available navigable depth.

IMPROVEMENT OF THE JAMES AND MARY REACH.

The peculiar conditions of the James and Mary reach have been already fully investigated under the heading of "Deterioration of the James and Mary Reach," pages 50 to 57; and they are illustrated by Plates 7 and 8. The methods, accordingly, of remedying the proverbial defects of this changeable and dangerous reach, which presents the greatest obstacles to the navigation of the Húgli, and which appears to be deteriorating, alone remain to be considered.

Proposals made for improving the James and Mary Reach.—Various suggestions have been made for the improvement of this reach. Mr. Leonard considered that an improvement might be effected by diverting the flow of the Rupnarain into the Haldia, and also by increasing the discharge of the Damuda into the Húgli at Fulta by impounding its flood waters for a time in reservoirs;* whilst Mr. Longridge and others have expressed the opinion that the diversion of the whole flow of the Damuda into the Rupnarain would effect an improvement in the James and Mary reach. † Mr. Brooks advocated evading the obstacle of the James and Mary Sands by making a new channel for the Húgli across the land to the east of Húgli Point, starting from the middle of the reach between Anchoring Creek and Nurpur, and emerging about opposite the Kukrahati crossing in the reach below. ‡

Mr. Leonard eventually proposed, in his report, the construction of one mile of brushwood spur from Fulta Point, followed by a mile of training wall of burnt clay, § which would have brought his training works down only slightly further than opposite Anchoring Creek, though on the general plan of the river they are shown nearly three miles in length. Sir Charles Hartley, to whom Mr. Leonard's memorandum of 1864 was submitted for his opinion, whilst agreeing with Mr. Leonard as to the value of an increased discharge from the Damuda into the Húgli at Fulta, proposed the construction of an "isolated work" or "artificial island," apparently to be placed along the James and Mary Sands, composed of rubble stone carried up to half-tide level, having a maximum length of nearly two miles. ‖

* "Report on the River Húgli," by Hugh Leonard, 1865, p. 26.

† Proceedings Inst., C. E., Vol. XXI, p. 23.

‡ "Lecture on the Húgli," by W. A. Brooks, United Service, Inst., 1865.

§ "Report on the River Húgli," p. 32.

‖ *Ibid.*, Appendix, "Opinion of Sir Charles Hartley on the Improvement of the River Húgli," 1864, pp. 32 to 35.

Recently, when in November 1895, the rapid shoaling of the Eastern Gut bar threatened to stop the passage of vessels, it was urged that the dredging of the bar should be undertaken, with the object of re-opening the river.

Consideration of Proposals for diverting the present flow of the Rivers.—An increase in the discharge of the Damuda into the Húgli opposite Fulta, by preventing the escape of its floods into the Rupnarain by means of either reservoirs or embankments, would, evidently, on account of the conditions affecting the channel in the upper part of the James and Mary reach, improve the flow down the Ninan Channel and into the Eastern Gut, and prevent the periodical formation of the Ninan bar, owing to the great augmentation that would be produced in the influence of the Damuda on the Húgli current during the freshets, as well as the increase in the discharge into the reach past Fulta Point. The formation, however, of reservoirs to store up for a time the large floods of the Damuda, or the enclosing of the river along several miles with sufficiently high and strong embankments to retain its floods, would involve works too extensive and costly to be undertaken merely for the improvement of a single reach of the Húgli, especially as the navigable channel would not thereby be secured against the formation of the Eastern Gut bar during the dry season.

The diversion of the whole of the discharge of the Damuda into the Rupnarain would be a less costly work ; but this change appears to be at present in progress from natural causes. Moreover, though this diversion, and the resulting silting up of the bed of the Damuda, would promote the formation of a channel towards the Western Gut, it is very doubtful, for the reasons given previously in dealing with the condition of the reach, whether an improved stable channel would be thereby secured.

The formation of a new channel for the Húgli, avoiding the James and Mary Sands and the bend round Húgli Point, would be too expensive an undertaking, especially as the cut would have to be commenced near Fulta Point instead of just above Nurpur, in order to avoid the formation of the Ninan bar, and as the abandoned channel would have to be closed on the opening of the cut, so as to make the flood tide flow up the new channel, instead of following its present course as it otherwise would do to a great extent. The prohibitive cost, however, alone precludes a considerable improvement in the course and condition of this part of the Húgli, by cutting a curving channel for it from Fulta Point to Diamond Harbour.

The diversion of the Rupnarain into the Haldia would be very inexpedient, irrespectively of its great cost, for this would deprive the river and estuary of a very large fresh-water discharge from Gewankhali to Haldia Point, which would lead to the formation of a bar at the Kukrahati crossing, the shoaling of Diamond Harbour, and the extension of Diamond Sand. The improvement, moreover, of the Eastern Gut bar, anticipated by Mr. Leonard from such a work, would not be likely to be realised, for this bar is not formed by the freshets, but by the conflicting action of the flood tide, running at right angles to the Eastern Gut during the dry season. In addition, this diversion would have no

influence on the Ninan bar, which did not form an obstruction to navigation when this question was raised.

The one river diversion, if it was practicable, which would, undoubtedly, benefit the Húgli, not merely along one reach, but between Calcutta and Húgli Point, and also higher up, would be the restoration of the flow of the Damuda to the old channel and outlet near Noaserai, which it is believed to have formerly followed.

Dredging for improving the James and Mary Reach.—Dredging in recent years has been increasingly employed for the improvement of rivers ; and it has rendered such great services to navigation, sometimes exceeding anticipations, that in the case of most river ports, it is now regarded as an indispensable aid for maintaining and increasing their accessibility. Dredging is most serviceable where it is carried on in general conformity with the course of the currents, serving to guide and facilitate their flow, and providing a depth which the currents, though not powerful enough to produce by scour, are able to maintain when formed. Though, however, dredging has sometimes been successfully applied to the deepening of an approach channel across a sandy foreshore on the sea-coast, exposed to littoral drift, as, for instance, at Calais, Dunkirk, and Ostend, it is not well suited for deepening channels subject to frequent and abrupt changes owing to periodical variations in the direction and force of the currents, more especially where, owing to the volume of alluvium carried down by the river, a channel is rapidly silted up when abandoned by the currents. This latter description represents the condition of the James and Mary reach, for the upper channel varies in direction with the strength of the freshets, as well as with the seasons ; and the freshets being charged with alluvium from the uplands, and the rapid flood tide bringing up sediment from below, the Eastern Gut is scoured out by the freshets which deposit sand in the Western Gut, whilst in the dry season the flood tide scours out the Western Gut, and more or less shoals the Eastern Gut, and forms a bar across its lower end. Moreover, the extensive sandbanks and shoals in mid-river do not merely change their shape and extent from time to time, but actually shift their position with the seasons, owing to the variable influences of the currents in the reach at different periods of the year, Plate 7.

Dredging might, indeed, be adopted with advantage, in an emergency, for opening out a passage across a suddenly formed narrow shoal, though the Eastern Gut bar is unfavourably situated for dredging operations, owing to the cross currents in the locality ; but in view of the variable nature of the currents in the reach and the resulting changes in the channels, and the shifting of the vast masses of sand which have accumulated in the reach in proportion to the progressing increase in its width, the maintenance of an adequately deep navigable channel through the reach by dredging alone would at times be impracticable. Moreover, though the depth of the channel might be somewhat improved by dredging during the dry season, the work would have to be commenced over again each year regularly ; the improvement would not be commensurate with the cost ; and the deterioration of the reach by widening

would continue unchecked. Under these circumstances, it does not appear at all advisable to attempt to improve the navigable condition of the James and Mary reach by dredging alone.

Training Wall for improving the James and Mary Reach.—The only remaining system of improvement, applicable to the James and Mary reach, to be considered, is the training of the channel. It is evident that the object to be aimed at, in such a situation, by means of training works, is to guide the descending current and the flood tide into a single channel, so as to put a stop to the successive opening out and silting up of each channel in turn, and to combine the present conflicting forces of freshets and flood tide in deepening the same channel.

The isolated training wall which was proposed by Sir Charles Hartley, in his anxiety not to reduce to any appreciable extent the tidal capacity of the reach, does not comply with the above essential condition, and was designed with the object of increasing the scour in the Eastern and Western Guts, and thereby deepening the channels, which was to be aided by dredging. As, however, it was not proposed in this design to close either the Eastern or Western Gut, these channels, though somewhat regulated by the intervening training wall, would have been still subject to the seasonal changes of being alternately scoured out and silted up ; and the Eastern Gut would have remained the navigable channel, with its awkward crossing below Húgli Point ; whilst the scheme naturally had no reference to the Ninan bar, which at that period offered no obstruction to navigation. The opinion, however, it must be borne in mind, was merely based on a perusal of Mr. Leonard's memorandum of 1864, written previously to his report, and the indications furnished by the somewhat imperfect surveys of the river made more than thirty years ago.

The training works subsequently proposed by Mr. Leonard in his report, were designed to lead the descending current gradually from about Fulta Point towards the Western Gut, which it was proposed to adopt as the navigable channel. These works, however, whilst fulfilling the condition of directing the freshets and flood tide into one channel, which is absolutely necessary for the satisfactory improvement of the James and Mary reach, were not designed to be carried far enough down the reach ; for the length of the training works, according to the estimated cost, was only two miles from Fulta Point downwards, extending just below Anchoring Creek, and therefore not sufficiently far to ensure the diversion of the upper navigable channel into the Western Gut, or to make the descending current adequately scour the western side of the central shoal to provide a large enough channel for the concentrated currents. Moreover, the system of spurs, proposed to be employed for half of the training works, though formerly often adopted with a view to economy, and still used as subsidiary works and dipping cross dykes in non-tidal rivers, have for some time past been abandoned for training tidal rivers, in favour of longitudinal training walls.

Line adopted for the proposed Training Wall.—Every consideration points to the importance of adopting the Western Gut as the navigable channel along the lower portion of the James and Mary reach, in spite of the small depth which

it has possessed generally for a long time past, owing to the great widening of the reach. In the first place, it is most important not to impede in any way the run of the flood tide up the Húgli, as constituting the principal means of maintaining the navigable depth of the channel during about two-thirds of the year; and the improvement of the Western Gut would most effectually promote the influx of the flood tide, and far more than compensate for any reduction in the tidal capacity of the reach itself by the accretion which must occur at the back of the training wall. The freshets, indeed, will eventually pass down the river in whatever course they may be directed; whereas the flood tide only flows up the river in proportion to the accessibility of the channel provided for it. The freshets, accordingly, must invariably be directed by any training works along the Húgli into the flood-tide channel. The Eastern Gut, moreover, is directly at right-angles to the course of the rapid currents in front of its outlet below Húgli Point, which is extremely inconvenient for navigation; and, generally, there is more or less of an obstruction across the channel at the crossing between the outlet of the Eastern Gut and the deep channel along the right bank below, Plate 7. The Western Gut, on the contrary, is in the direct run of the flood tide up the reach, which prevails for about eight months in the year; and the Western Gut generally possesses an adequate depth at its outlet; and its issuing current is guided round the bend, into the deep channel along the Gewankhali shore, by the discharge from the Rupnarain. The defective portion of the Western Gut is, indeed, at about the middle of the reach, where it can be effectually dealt with by training works; whereas the bar of the Eastern Gut extends into the river below the reach, where training works cannot be carried out.

For the above reasons, it is evident that the improvement of the James and Mary reach can only be effectually accomplished by training the channel of the freshets and ebb tide, from below Fulta Point, by a gradual bend into the Western Gut. Moreover, the width of the low-water channel must not be reduced anywhere within the limits of the channel through the narrow neck at Fulta Point in order not to impede the progress of the flood tide up the deepened channel; and, for the same reason, the training wall should be kept at as low a level as practicable, consistently with its leading the descending current into the Western Gut. These are the principles upon which the training wall shown on Plate 7, Fig. 4, and Plate 8, Figs. 8 and 9, have been designed. The training wall, slightly over 4 miles in length, extends from Fulta Point nearly down to the outlet of the Western Gut; and the concave bend of the river side of the training wall will guide the freshets along it towards the Western Gut, and by leading them against the sandbank in mid-river will make them enlarge the Western Gut on its eastern side by scour. The training wall shown on Plate 7, Fig. 4, has been made straight towards its lower end, in order that, after bending above to secure a deep channel along the present crossing, the channel may not be unduly narrowed at its lower part; and the end portion of the training wall has been curved outwards from the channel, in a south-easterly direction, in order to prevent undue scour at the extremity by the sudden release of the confined current, to facilitate the outflow of the current into the reach below in a suitable direction at the bend round Húgli Point, and to afford an ample entrance for the influx of the flood tide up

the trained and deepened channel. The continuous deep channel which will be thereby formed all along the reach, will resemble in a more direct, wider, and deeper form, the channel between Ninan and the Western Gut, which opened out in November 1895 on the sudden shoaling of the Eastern Gut, and continued to be used as the navigable channel till March 1896, and which two of the most experienced pilots of the Húgli informed me last February was a much more convenient and safer channel for the passage of vessels than the ordinary navigable channel by the Eastern Gut. The proposed training wall, moreover, will prevent the periodical formation of the Ninan bar after seasons of high freshets, and will arrest the gradual deterioration of the navigable condition of the reach, resulting from the continued erosion of the eastern bank.

The height of the proposed training wall has been fixed at low-water of ordinary spring tides, Plate 8, Figs. 8 and 9, as the favourable concave line of the training wall guiding the powerful freshets should succeed in producing a sufficient scour to clear out the channel, which could be very advantageously aided at the commencement by a sand-pump dredger ; and the lower the wall can be kept, the less will it interfere with the tidal capacity of the reach.

Materials to be used for the proposed Training Wall.—Rubble stone, deposited at random in a continuous mound, probably forms the best training wall. Where, however, stone is difficult to obtain of adequate size, and the extent of the work is considerable and brushwood abundant, mattresses of fascines bound together and weighted with stones, broken bricks, or clay (preferably in bags), have been extensively used for river works, especially in Holland and the United States. These mattresses have been used within the last thirty years, not merely in training the sheltered portions of rivers in temperate regions, but also in guiding rivers into the sea, of which the first instance was the Jetties projecting into the North Sea at the mouth of the Maas ; and the system has since been extended to sea works in tropical countries, as, for example, the Jetties conveying the South Pass outlet of the Mississippi into deep water in the Gulf of Mexico, and the Charleston, Galveston, and Tampico harbour works.

As stone is scarce in the neighbourhood of Calcutta, and brushwood is readily obtainable in uncultivated districts adjacent to the river, it is proposed that the training wall should be constructed with fascine mattresses, capped on the top by a row of brickwork blocks, Plate 8, Fig. 9. This form of construction, besides being dictated by considerations of cost, will prove advantageous, on a somewhat unstable bottom of fine sand, in preventing undue settlement, by the lightness of the structure and its broad, yielding base. An allowance of some feet has been made for settlement, as shown by the dotted line below the bed of the river along the longitudinal section of the training wall, especially along the shallower portions of the concave wall where erosion is most likely to occur near the base of the training wall, Plate 8, Fig. 8. Provision has also been made to prevent erosion taking place too close to the mass of the training wall, by making the increase in the width of the successive layers of mattresses greater on the channel side, and giving a projection of 6 feet each to the two bottom layers of mattresses all along the traininig wall on the side of the

channel. By stepping out the mattresses beyond the termination of the wall at the lower end, as well as curving the training wall away from the channel, erosion from scour round the end will be prevented. The training wall, being always immersed in water, will not be subject to the decay which all classes of timber, when alternately wet and dry, undergo. Moreover, the interstices in the mattresses will be rapidly filled up with sand and mud from the river ; the outer surfaces of the training wall will be soon coated with deposit ; and the inner face will be covered with the accretion which must necessarily take place between the training wall and the eastern bank below low-water. The line of the training wall will have to be marked at intervals by iron beacons rising above high-water, on which lamps supplied with compressed oil gas could be placed if it should be desired to navigate the reach at night.

Estimated Cost of the Proposed James and Mary Training Wall.—The cost of fascine mattresses in works in Holland and the United States, as actually executed, per cubic yard, was as follows : The fascine mattresses in the embankment across Lake Y, shutting off the Amsterdam Ship-Canal from the Zuider Zee, cost 5*s.* 1*d.* per cubic yard. The fascine mattress jetties forming the new outlet for the River Maas into the North Sea at the Hook of Holland, cost 10*s.* 5*d.* per cubic yard, in a position fully exposed to the sea. The fascine mattress training works in the Hollandsch Diep cost 4*s.* 2*d.* per cubic yard. The fascine mattress jetties at the outlet of the South Pass of the Mississippi, extending $2\frac{1}{4}$ and $1\frac{1}{2}$ miles into the Gulf of Mexico, cost about 7*s.* per cubic yard ; whilst similar works at Tampico Harbour, also on the Gulf of Mexico, cost 6*s.* 2*d.* per cubic yard. The jetties on the North Sea and the Gulf of Mexico are in much more exposed situations than the James and Mary reach in the Húgli ; and wages would be much higher in Holland and the United States than in India. In consideration, however, of the strong and variable currents in the James and Mary reach, the precautions that would have to be adopted, and to make allowance for very strong mattresses, it will be assumed that the training wall in the James and Mary Reach would cost 7*s.* per cubic yard ; and to allow an ample margin for a possible increase in the amount of settlement resulting from erosion, especially in the shallower portions, necessitating additions to the training wall, the ordinary addition of 10 per cent. for contingencies will be raised to 15 per cent. in this instance. Proceeding, accordingly, on this basis, and assuming that as all the materials will be obtained, and all the work executed in India, the rupee may be taken at par value, and the cost therefore of the mattress work to amount to Rs. $3\frac{1}{2}$ per cubic yard, the estimate will be as follows :—

	Rs.
Fascine Mattresses in Training Wall, 451,400 cubic yards at Rs. $3\frac{1}{2}$ per cubic yard ...	15,79,900
Brickwork Blocks for Capping of Training Wall, 521,100 cubic feet at Rs. 40 per 100 cubic feet	2,08,440
	17,88,340
Contingencies at, say, 15 per cent.	2,68,251
	20,56,591
Cost of James and Mary Training Wall ...	Rs. 20,57,000

By adopting the modification shown by dotted lines on the chart and longitudinal section, Plate 7, Fig. 4, and Plate 8, Fig. 8, the cost of the training wall might be reduced to Rs. 15,55,000 ; but it is not as satisfactory a course as the first design.

Remarks on the proposed James and Mary Training Wall.—The construction of the proposed training wall will provide a good, direct, stable channel of ample depth through the James and Mary reach, in place of the present shifting channel, subject to obstruction by bars at Ninan, and at the lower end of the Eastern Gut, at different periods. The new channel, moreover, will be free from the difficulties of navigation resulting from the cross currents at the outlet of the Eastern Gut, and exempt from the dangers to navigation presented by the James and Mary Sands. In the event, indeed, of the training wall being carried out on the lines indicated, this reach, instead of remaining the greatest and most dangerous obstruction to navigation between Calcutta and the sea, will become one of the most convenient and safest parts of the river, with the flood and ebb tides following the same course throughout the reach. The works, in fact, will bring back this reach, with improvements, to the sort of condition it was in when the Western Gut was frequently the navigable channel, and from which it has been deteriorating for a long period by the progressive increase in its width. The regulated and deepened channel will greatly facilitate the flow of the flood tide up to Fulta ; and, in spite of the reduction in tidal area which may eventually result from the raising of the accretion along the eastern bank behind the training wall above low-water, it will considerably improve the tidal condition of the reach, and accelerate the influx of the flood tide into the reaches above.

MOYAPUR TRAINING WALL.

Though the Moyapur crossing is in a much less defective condition than the James and Mary reach, and dredging would be more capable of maintaining an adequately deep channel through the shoal than in the latter reach, the conditions of the Moyapur reach, already described on pages 48 and 49, are not favourable to the maintenance of a channel dredged through the shoal. Dredging would have to be frequently carried on, owing to the variable direction of the currents according to the seasons ; and at times, towards the close of the freshets, it might be unable to keep open an adequately deep channel. Moreover, dredging would not arrest the deterioration in the channel at the crossing, resulting from the increasing width of the river at that part. The most satisfactory and most permanent improvement of this reach would be to make the currents deepen the channel over the crossing by scour, by reducing the excessive width of the river at that place.

Line proposed for the Moyapur Training Wall.—To avoid impeding at all the influx of the flood tide up the Moyapur reach, it is necessary to direct the current of the freshets, keeping close along the right bank, into the flood-tide channel running along the opposite bank. The concave curve, accordingly, of the right bank, which changes to a straight line a little above the crossing, must be continued towards the crossing till it has narrowed the channel sufficiently to

direct the freshets and the ebb tide across river into the flood-tide channel. This is the principle upon which the line of the proposed training wall, as shown on the chart, Plate 6, Fig. 3, has been laid down ; and like the James and Mary training wall, the Moyapur training wall has been given a convex bend towards its termination, turning it away from the channel at its lower end to guide the channel a little further down without reducing the width. The deep channel at present existing along the right bank will be continued along the concave bend of the training wall, till it joins the flood-tide channel ; and this crossing channel, formed by the freshets, will be followed by the flood tide in the dry season, and maintained by the ebb tide. The Moyapur bar will be thus scoured away ; and a continuous channel of over 3 fathoms in depth at the lowest low-water will be formed at the crossing, following approximately the course of the navigable channel in the chart of 1883, Plate 6, Fig. 1.

As the channel formed by the freshets is so deep in this part, the current will be sufficiently directed by the training wall, even if it is not raised to the level of low-water. It is, therefore, proposed, in this instance, to stop the high training wall at 6 feet below the lowest low-water, which, besides reducing its cost, will prevent any loss of tidal capacity in this comparatively narrow reach, Plate 6, Figs. 7 and 8. In other respects, the Moyapur training wall will be precisely similar to that of the James and Mary.

Estimated Cost of the Moyapur Training Wall.—As the site of the Moyapur training wall is considerably less exposed to variable currents and shifting sands than the James and Mary reach, the cost of the fascine mattress work may be put at Rs. 3 ; and 10 per cent. for contingencies ought to be ample. The cost, accordingly, of the Moyapur training wall on this basis will be as follows :—

	Rs.
Fascine Mattresses in Training Wall, 137,300 cubic yards at Rs. 3 per cubic yard	4,11,900
Brickwork Blocks for Capping of Training Wall, 134,640 cubic feet at Rs. 40 per 100 cubic feet	53,856
	4,65,756
Contingencies at 10 per cent.	46,575
	5,12,331
Cost of Moyapur Training Wall ... ... Rs.	5,12,400

Remarks on the Moyapur Training Wall.—The cost of the Moyapur training wall is large in proportion to its length, of only slightly over a mile, owing to the depth of the river along the proposed site, ranging from over 3 fathoms to over 5 fathoms below the lowest low-water, except quite close to the shore. The training wall, however, will effectually remove the Moyapur bar, and will facilitate the flow of the flood tide up the deepened channel, without reducing at all the tidal capacity of the reach. In fact, if the Moyapur and James and Mary training walls are carried out, the Royapur crossing, with a minimum depth over the shoal of 20 feet at the lowest low-water, will become

the shallowest plaee in the navigable channel of the Húgli between Caleutta and the Balari bar. The differenee, however, between the improved eondition thereby gained and the present state of the river, is not the only measure of the benefits that would be conferred on navigation by the proposed works ; for the diffieulties and dangers of the James and Mary reaeh, irrespeetively of the bars, would be removed ; and the tidal condition of the river along the two reaehes, and in their neighbourhood, would be materially improved.

DREDGING IN THE HÚGLI ESTUARY.

Dredging might be expedient to a small extent at the Royapur erossing; over the eentral shoal of the James and Mary reach, during the construction of the training wall, to assist in opening out the new channel ; and at any place in the Húgli between Calcutta and Fulta Point, where a small increase in the width or depth of the navigable channel might at any time appear desirable. By lowering the shoal at the Royapur crossing about 2 feet after the close of the freshets, the available depth, after the completion of the James and Mary and Moyapur training walls, might be increased from 20 to 22 feet, at the lowest low-water in the navigable channel between Calcutta and the Balari bar. Beyond this depth, however, the shoals opposite Hastings and Fulta Sand would begin to present obstructions, Plate 5, Fig. 27.

Only a few years ago,dredging in the Húgli estuary might well have been deemed useless for appreciably improving the navigable channel ; and it might still be so considered if the channel had remained as changeable as in the earlier part of this eentury, and till after 1864. Great improvements, however, have been lately effected in sand-pump dredgers, and the cost of dredging sand has been very greatly reduced within reeent years ; so that works which would have been regarded as far too onerous only a few years ago, are now readily undertaken and successfully accomplished. The Mersey bar, though presenting no similarity in its origin to the Húgli bars, furnishes a eonspicuous instance of a deep channel being formed in a very exposed situation, by sand-pump dredgers, through a line of sandbanks stretching across from the Dee to the Ribble estuaries, where vast masses of sand under the action of the sea tend to elose up the outlets of the Mersey, and which some engineers declared to be impraetieable as reeently as 1890.

Under far more similar conditions to the Húgli, but without the advantages of tidal aetion, dredging is being carried out regularly in the jetty channel of the South Pass of the Mississippi, to maintain the requisite navigable depth of 26 feet with a maximum depth of 30 feet ; and dredging has been employed during the last three or four years to preserve the proper navigable depth in the shifting channel aeross the bar,beyond the outlet of the South Pass, in the almost tideless Gulf of Mexico, where enormous deposits continually tend to aceumulate from the great quantity of alluvium diseharged by the Mississippi. Moreover, in the autumn of 1894, dredging was commenced on the bar outside the Sulina mouth of the Danube in the Black Sea, formed by the silty alluvium brought down by the river ; and the depth in the channel over the bar was inereased from 20½ feet, the depth in 1894, to 24 feet by September, 1895,

by a bucket dredger. In 1894, the annual dredging of the shifting sand bars of the Mississippi below Cairo, by means of a suction dredger, was commenced under the direction of the Mississippi River Commission * ; and in March last the trials of a new dredger, constructed for the Commission, with a central suction pipe surrounded by revolving cutters, showed that this dredger could raise from about 4,000 to 7,800 cubic yards of sand per hour. †

Aims of the Dredging proposed in the Húgli Estuary.—Some improvement, accordingly, of the depth of the navigable channel through the Húgli estuary might reasonably be expected from the employment of a sand-pump dredger of large capacity for work, considering the remarkable stability of the channel for many years past, and that the currents follow the course of the channel. In the existing condition of the bars in the estuary, a 3-fathom channel could not be provided throughout at a reasonable cost ; and unless the estuary should return again to the excellent state shown on the chart of 1889-90, the improvements by dredging would have to be restricted to certain objects. In the first place, when any bar is raised above its normal height for a moderate width, dredging might be employed for lowering it to the depth over the other bars. Moreover, in the case of the Jellingham-Dredge bar, the current appears sufficiently powerful to displace the bar, without having adequate force to scour it from the channel; and it appears probable that if the bar was removed by a sand-pump dredger, it might not form again for some time to come; and the removal of the bar would tend to keep the current more thoroughly in the channel, and prevent its diversion into Kaukhali Roads. This, moreover, would promote the raising of the shoal between Gańgra and Kaukhali Sands, which would assist in preventing the re-formation of the bar. Dredging might also be very advantageously applied in aiding the opening out of a channel in course of formation, or which had been merely temporarily shoaled up. For instance, if one of the western channels alongside the Mizen Sand, or the Long Sand Channel, should continue to open out, so that it became necessary, owing to the shoaling of the Middleton bar, to abandon the Gasper Channel, dredging might very usefully be employed in deepening the new channel during its transition state. On the other hand, if the Western and Long Sand Channels should shoal again, as appears rather likely from the chart of 1895-96, dredging would be extremely advantageous in opening up again the Eden Channel, which the current, especially during low freshets, might be powerless to effect, but which it could maintain after the causes of the shoaling had ceased to exist by the closing of the secondary channels. Moreover, the deepening of the Eden Channel, and the deposit of the dredged sand along its south-western edge, would hasten the shoaling of the branch channels, and materially assist in restoring the scour of the currents over the Middleton bar, and thereby improve the channel between Saugor Roads and the Gasper Channel. Dredging, accordingly, should be employed in the estuary for lowering narrow bars of abnormal height; for aiding the scour of the currents in the channel, and thereby increasing its stability as well as it depth ; for facilitating changes in the course of the channel when they have become

* "Report of the Chief of Engineers, U. S. Army," 1895, Part 6, pp. 3628—3639.

† "The Engineer," July 3rd, 1896, p. 18.

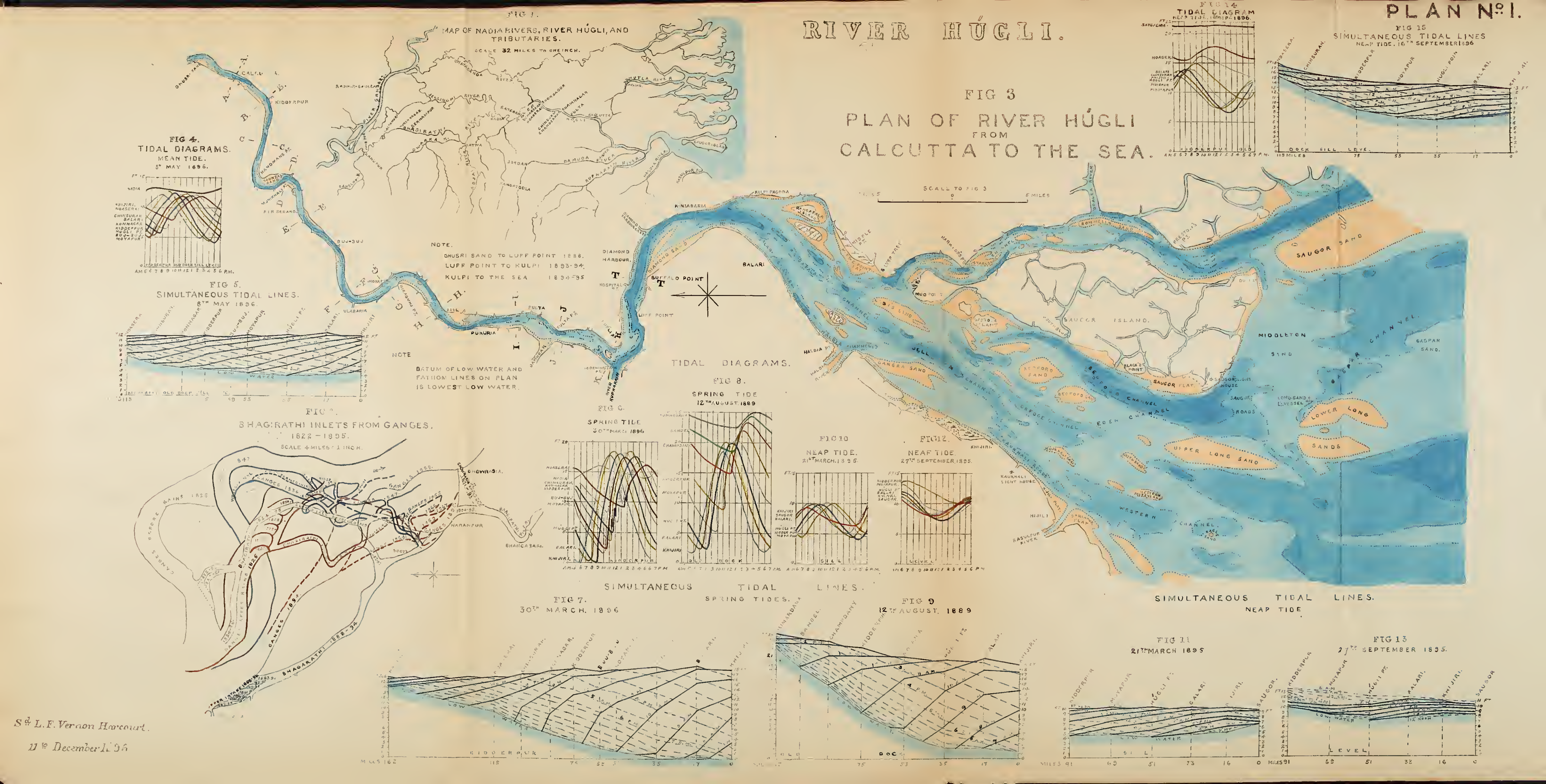
inevitable ; or for opening up the portion of a channel which has become shoaled from temporary causes. In fact, dredging might be very usefully employed in the Húgli estuary in assisting nature, and thereby gradually improving the navigable condition of the channel through the estuary.

Inexpediency of Training Works in the Húgli Estuary at present.—The only other means of improving the navigable channel through the Húgli estuary would be by training works, carried gradually down both sides of the central channel, with an enlarging width sea-wards. The improvement of the unstable Rangafala Channel could only be effected in this manner; but as the Balari and Haldia Channels provide a stable route for navigation at the present time, which has experienced a considerable improvement in the last few years, as compared with its condition in 1888 and previously, training works, which would have to commence near Kantabaria and be carried down as far as Haldia Island, and would involve a considerable expenditure, appear to be quite unnecessary at the present time.

Concluding Remarks.—In conclusion, a very careful study of all the available charts indicates that the Húgli possesses considerable natural capabilities for navigation ; that by training works in the Moyapur and James and Mary reaches its river portion could be greatly improved, and the deterioration at these two places arrested ; and that the navigable channel through the estuary, though less capable of improvement at a reasonable cost, might, owing to the fair stability of its course and the run of the currents along the main channel, be deepened to a moderate extent by a powerful suction dredger.

L. F. VERNON-HARCOURT.

The 11th December 1896.



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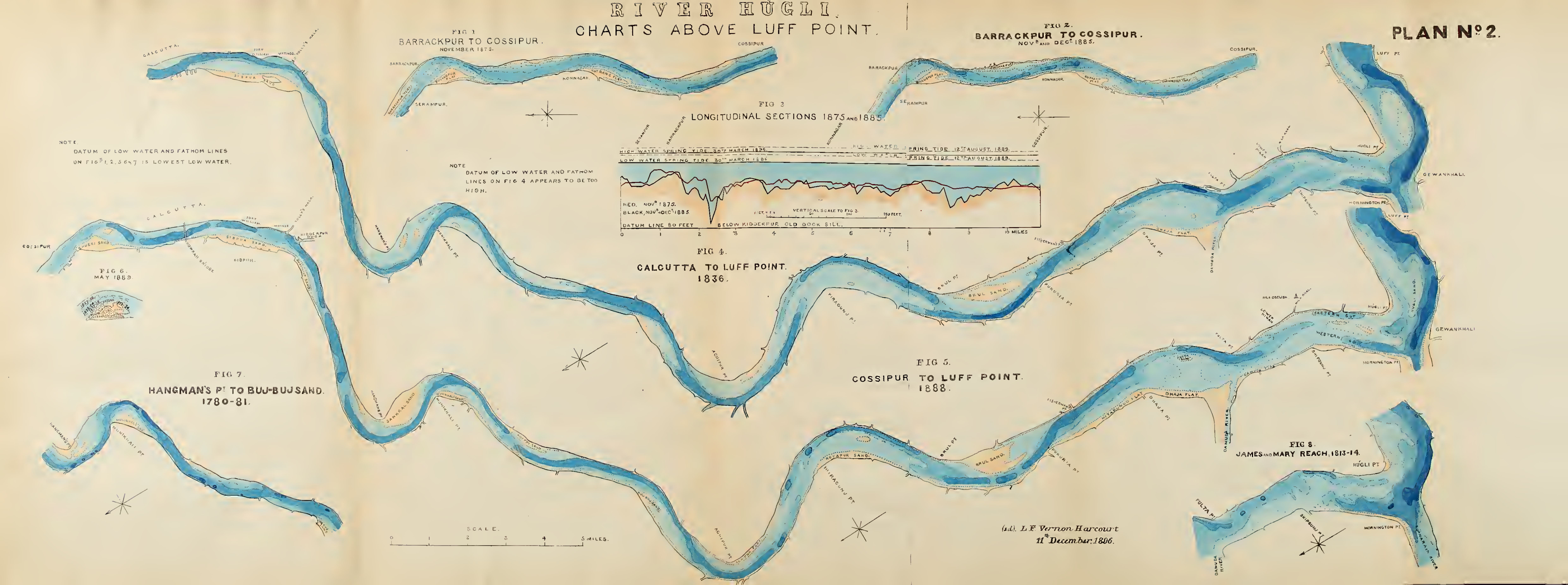
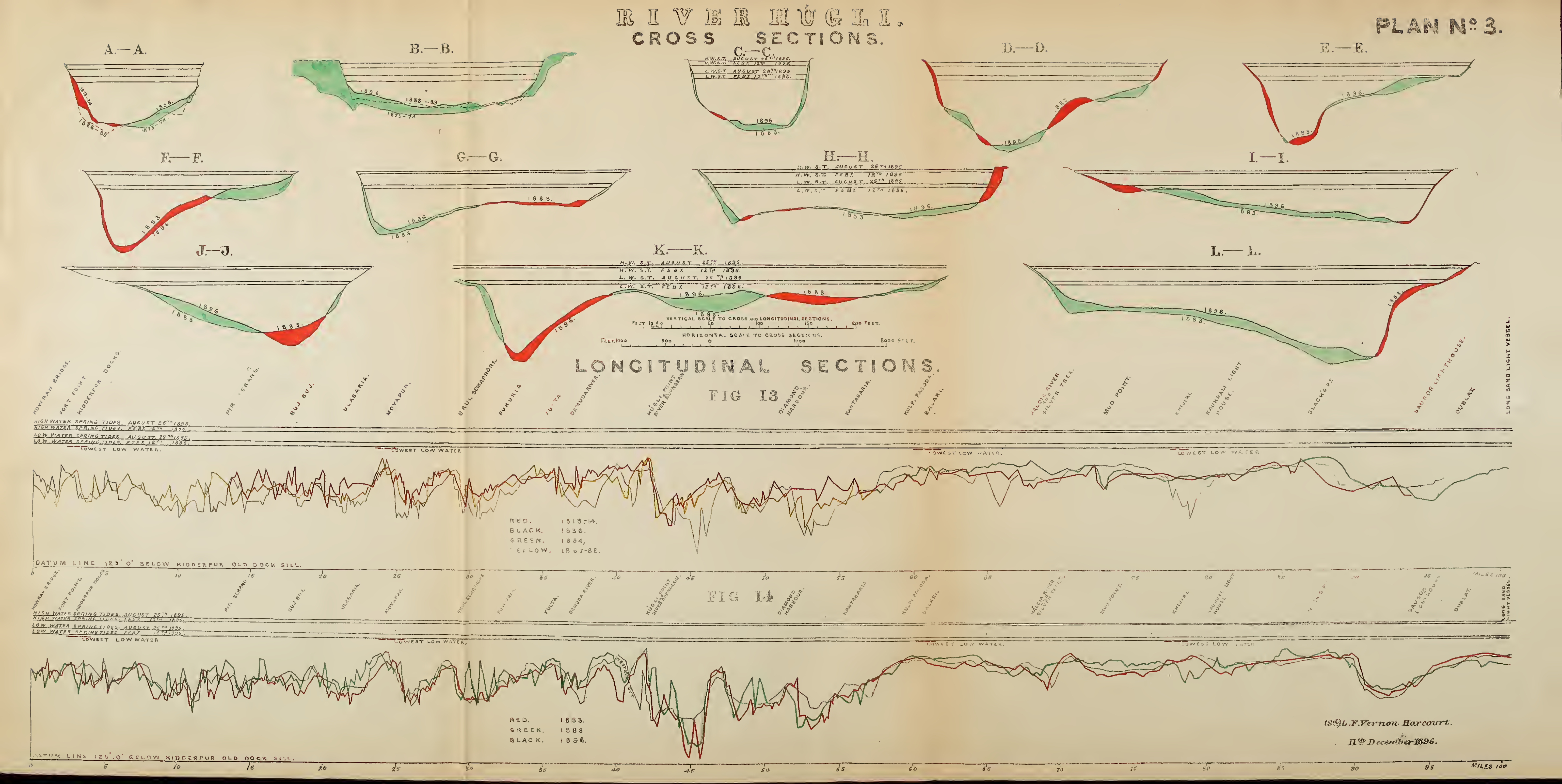
11th December 1896

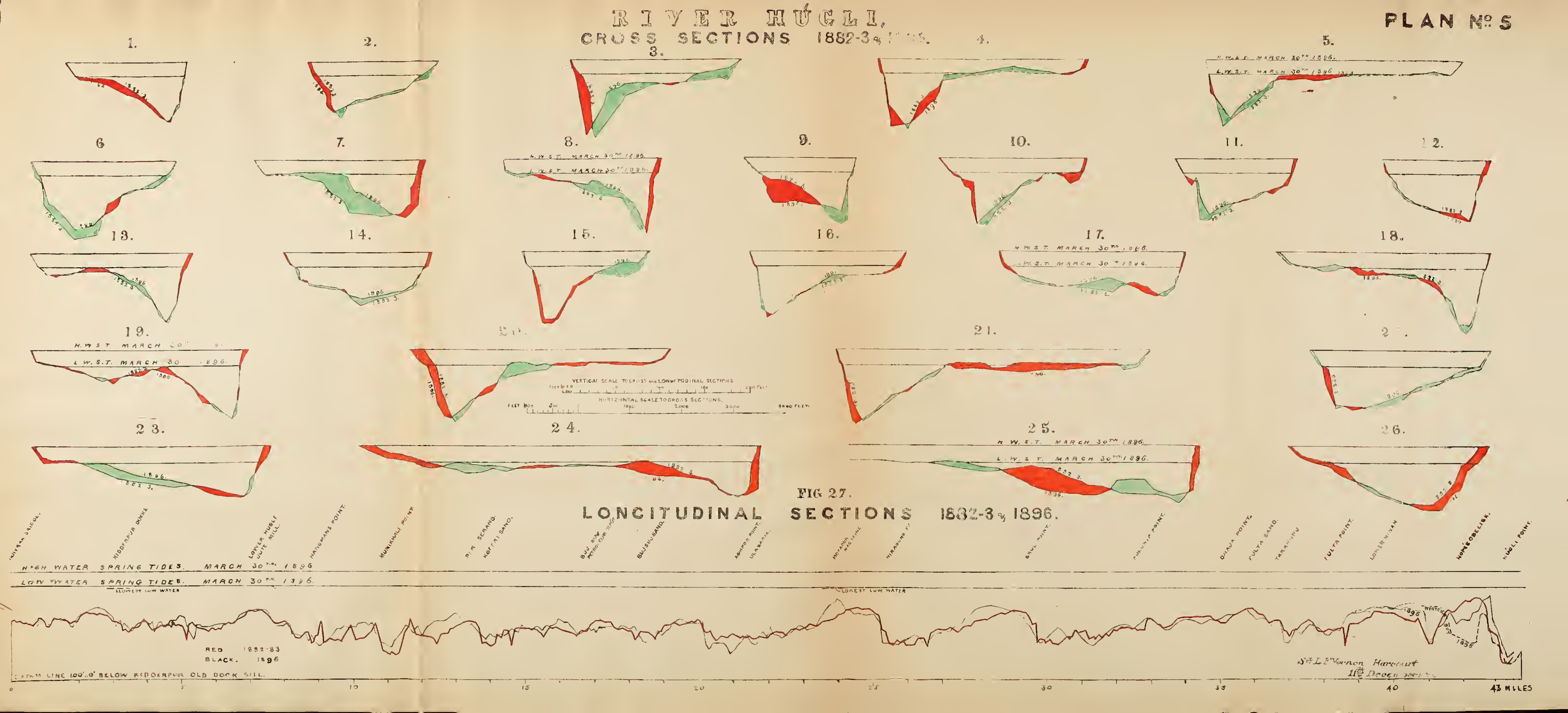

RIVER HUGLI.
CHARTS ABOVE LUFF POINT.
PLAN No. 2.
FIG 1.
BARRACKPUR TO COSSIPUR.
NOVEMBER 1875.
FIG 2.
BARRACKPUR TO COSSIPUR.
NOVR AND DECR 1885.
FIG 3.
LONGITUDINAL SECTIONS 1875 AND 1885.
HIGH WATER SPRING TIDE 30TH MARCH 1875.
HIGH WATER SPRING TIDE 12TH AUGUST 1889.
LOW WATER SPRING TIDE 30TH MARCH 1875.
LOW WATER SPRING TIDE 12TH AUGUST 1889.
RED, NOVR 1875.
BLACK, NOVR & DECR 1885.
VERTICAL SCALE TO FIG 3
DATUM LINE 80 FEET BELOW KIDDERPUR OLD DOCK SILL.
0 1 2 3 4 5 6 7 8 9 10 MILES
NOTE.
DATUM OF LOW WATER AND FATHOM LINES ON FIGS 1, 2, 5, 6 & 7 IS LOWEST LOW WATER.
NOTE
DATUM OF LOW WATER AND FATHOM LINES ON FIG 4 APPEARS TO BE TOO HIGH.
FIG 4.
CALCUTTA TO LUFF POINT.
1836.
FIG 5.
COSSIPUR TO LUFF POINT.
1888.
FIG 6.
MAY 1889
FIG 7.
HANGMAN'S PT TO BUJ-BUJ SAND.
1780-81.
FIG 8.
JAMES AND MARY REACH, 1813-14.
SCALE.
0 1 2 3 4 5 MILES.
CALCUTTA.
COSSIPUR.
BARRACKPUR.
SERAMPUR.
KONNAGAR.
HUGLI PT.
GEWANKHALI.
MORNINGTON PT.
LUFF PT.
FULTA PT.
BRUL PT.
BRUL SAND.
DHAJA FLAT.
DHAJA PT.
DAMUDA RIVER.
SHIPGUNJ PT.
PIRAGUNJ PT.
ACHIPUR PT.
MUNIKHALI PT.
HANGMAN'S PT.
KIDDERPUR DOCK.
HOWRAH BRIDGE.
SIBPUR SAND.
(sd). L.F. Vernon Harcourt
11th December, 1896.

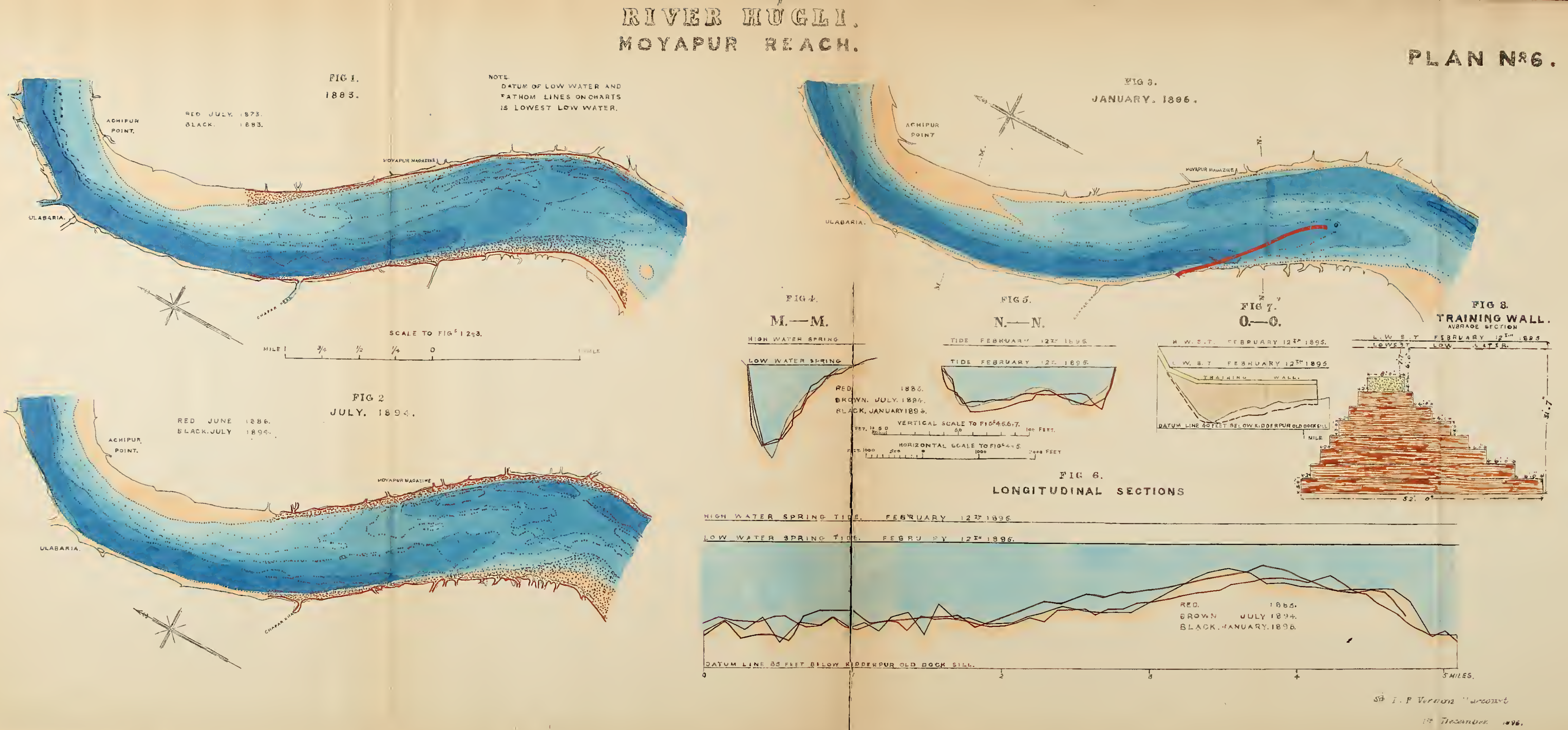

RIVER HÚGLI.
CROSS SECTIONS.
PLAN No. 3.
A.—A.
B.—B.
C.—C.
D.—D.
E.—E.
F.—F.
G.—G.
H.—H.
I.—I.
J.—J.
K.—K.
L.—L.
H.W.S.T. AUGUST 25TH 1895.
H.W.S.T. FEBY. 12TH 1896.
L.W.S.T. AUGUST 25TH 1895.
L.W.S.T. FEBY. 12TH 1896.
VERTICAL SCALE TO CROSS AND LONGITUDINAL SECTIONS.
FEET 10 0 50 100 150 200 FEET.
HORIZONTAL SCALE TO CROSS SECTIONS.
FEET 1000 500 0 1000 2000 FEET.
LONGITUDINAL SECTIONS.
FIG 13
HOWRAH BRIDGE.
FORT POINT.
KIDDERPUR DOCKS.
PIR SERANG.
BUJ BUJ.
ULABARIA.
MOYAPUR.
BAUL SEMAPHORE.
PUKURIA.
FULTA.
DAMUDA RIVER.
HÚGLI POINT RIVER RUPNARAIN.
DIAMOND HARBOUR.
KANTABARIA.
KULPI PAGODA.
BALARI.
HALDIA RIVER SILVER TREE.
MUD POINT.
KHIJIRI.
KAUKHALI LIGHT HOUSE.
BLACK'S PT.
SAUGOR LIGHTHOUSE.
DUBLAT.
LONG SAND LIGHT VESSEL.
HIGH WATER SPRING TIDES. AUGUST 25TH 1895.
HIGH WATER SPRING TIDES. FEBY. 12TH 1896.
LOW WATER SPRING TIDES. AUGUST 25TH 1895.
LOW WATER SPRING TIDES. FEBY. 12TH 1896.
LOWEST LOW WATER.
RED. 1813-14.
BLACK. 1836.
GREEN. 1854.
YELLOW. 1867-82.
DATUM LINE 125' 0" BELOW KIDDERPUR OLD DOCK SILL.
MILES 100
FIG 14
RED. 1883.
GREEN. 1888
BLACK. 1896.
DATUM LINE 125' 0" BELOW KIDDERPUR OLD DOCK SILL.
MILES 100
(Sd.) L. F. Vernon Harcourt.
11th December 1896.

RIVER HÚGLI,
SURVEYS OF 1882-3 & 1896.

PLAN Nº 4.

SR. L. F. VERNON HARCOURT
11TH DECEMBER 1896


RIVER HÚGLI,
CROSS SECTIONS 1882-3 & 1896.
PLAN No. 5
H.W.S.T. MARCH 30TH 1896.
L.W.S.T. MARCH 30TH 1896.
VERTICAL SCALE TO CROSS AND LONGITUDINAL SECTIONS
HORIZONTAL SCALE TO CROSS SECTIONS
FIG 27.
LONGITUDINAL SECTIONS 1882-3 & 1896.
KIDDERPUR DOCKS.
HANGMANS POINT.
MUNIKHALI POINT.
KOFFRI SAND.
ACHIPUR POINT.
ULABARIA.
FULTA SAND.
FULTA POINT.
HOOGLY POINT.
HIGH WATER SPRING TIDES. MARCH 30TH 1896
LOW WATER SPRING TIDES. MARCH 30TH 1896.
LOWEST LOW WATER
RED 1882-83
BLACK. 1896
DATUM LINE 100'.0" BELOW KIDDERPUR OLD DOCK SILL.
43 MILES

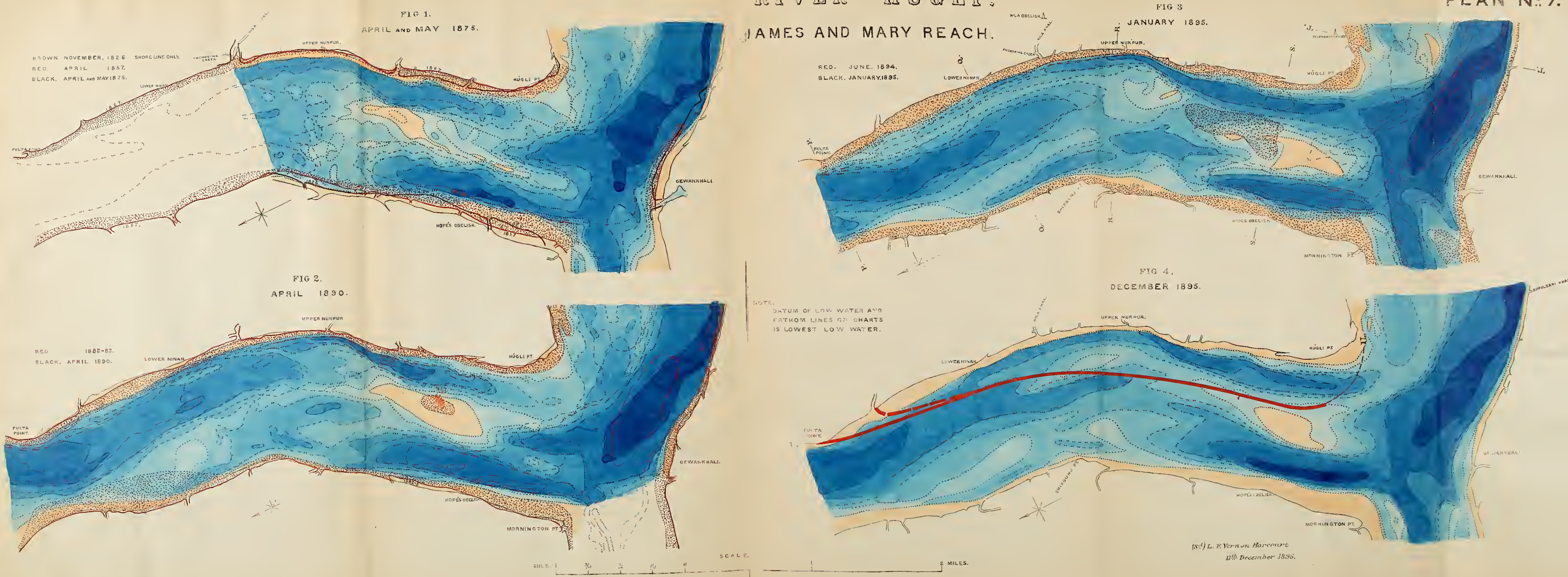


RIVER HUGLI.
MOYAPUR REACH.
PLAN No. 6.
FIG 1.
1883.
NOTE.
DATUM OF LOW WATER AND FATHOM LINES ON CHARTS IS LOWEST LOW WATER.
RED JULY 1873.
BLACK 1883.
ACHIPUR POINT.
MOYAPUR MAGAZINE
ULABARIA.
SCALE TO FIGS 1 2 & 3.
FIG 2
JULY. 1894.
RED JUNE 1886.
BLACK. JULY 1894.
FIG 3.
JANUARY. 1896.
FIG 4.
M.—M.
HIGH WATER SPRING
LOW WATER SPRING
RED 1883.
BROWN. JULY. 1894.
BLACK. JANUARY 1896.
FIG 5.
N.—N.
TIDE FEBRUARY 12TH 1895.
VERTICAL SCALE TO FIGS 4.5.6.7.
HORIZONTAL SCALE TO FIGS 4.5.
FIG 7.
O.—O.
H. W. S. T. FEBRUARY 12TH 1895.
L. W. S. T. FEBRUARY 12TH 1895.
TRAINING WALL.
DATUM LINE 40 FEET BELOW KIDDERPUR OLD DOCK SILL.
FIG 8.
TRAINING WALL.
AVERAGE SECTION
L. W. S. T. FEBRUARY 12TH 1895
LOWEST LOW WATER.
52'. 0"
FIG 6.
LONGITUDINAL SECTIONS
HIGH WATER SPRING TIDE. FEBRUARY 12TH 1895.
LOW WATER SPRING TIDE. FEBRUARY 12TH 1895.
RED. 1883.
BROWN JULY 1894.
BLACK. JANUARY. 1896.
DATUM LINE 86 FEET BELOW KIDDERPUR OLD DOCK SILL.
5 MILES.
Sd. L. F. Vernon Harcourt
December 1896.

RIVER HÚGLI.

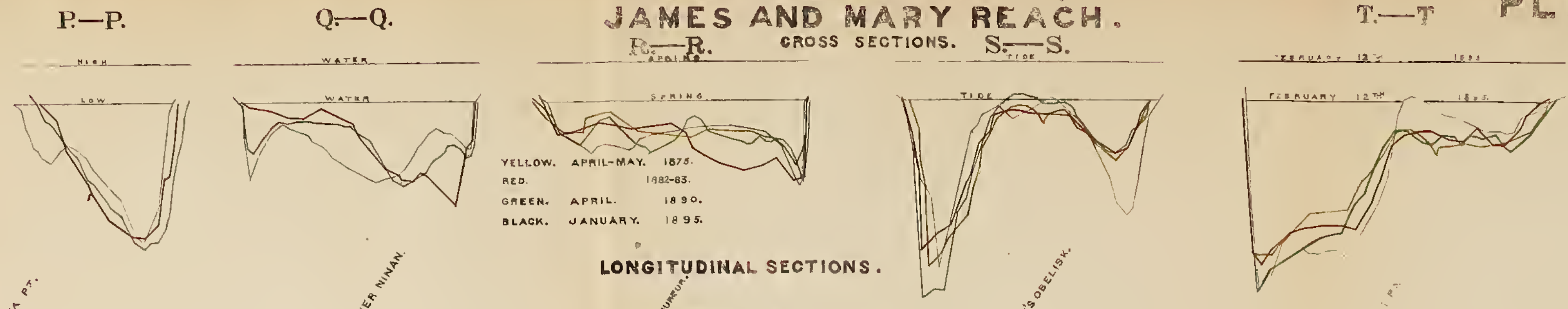
JAMES AND MARY REACH.

PLAN No. 7.



RIVER HÚGLI.
JAMES AND MARY REACH.
CROSS SECTIONS.

PLAN No 8.



LONGITUDINAL SECTIONS.

FIG 6.

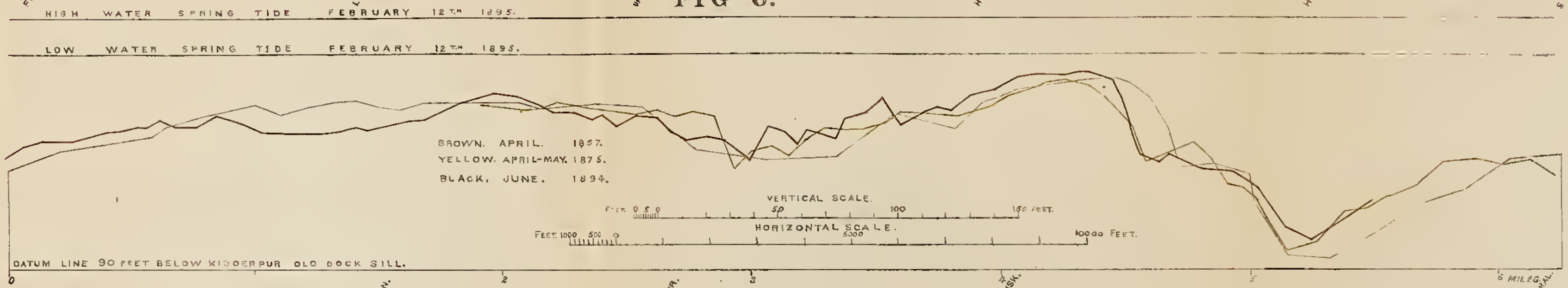


FIG 7.

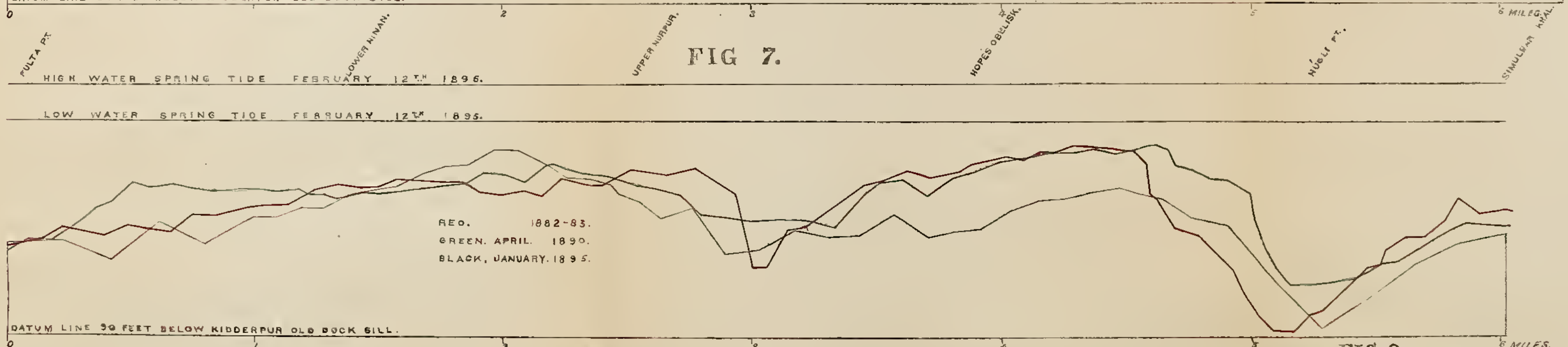


FIG 8.

U.—U.

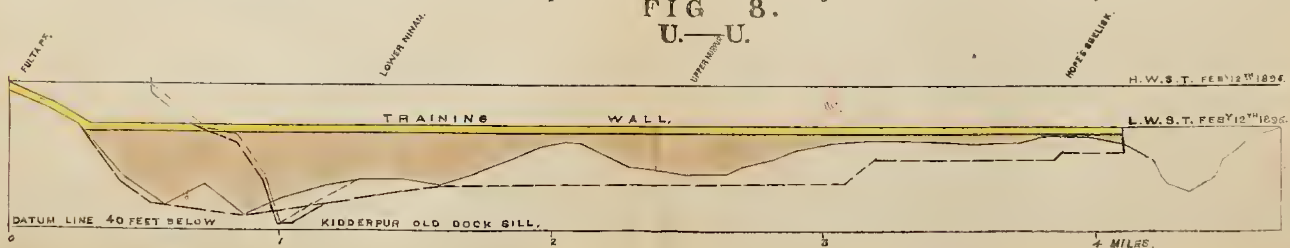
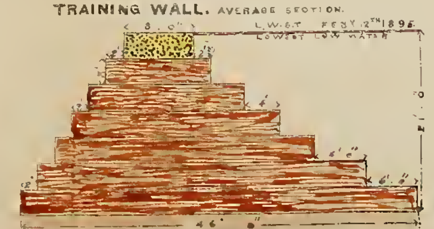


FIG 9.

TRAINING WALL. AVERAGE SECTION.



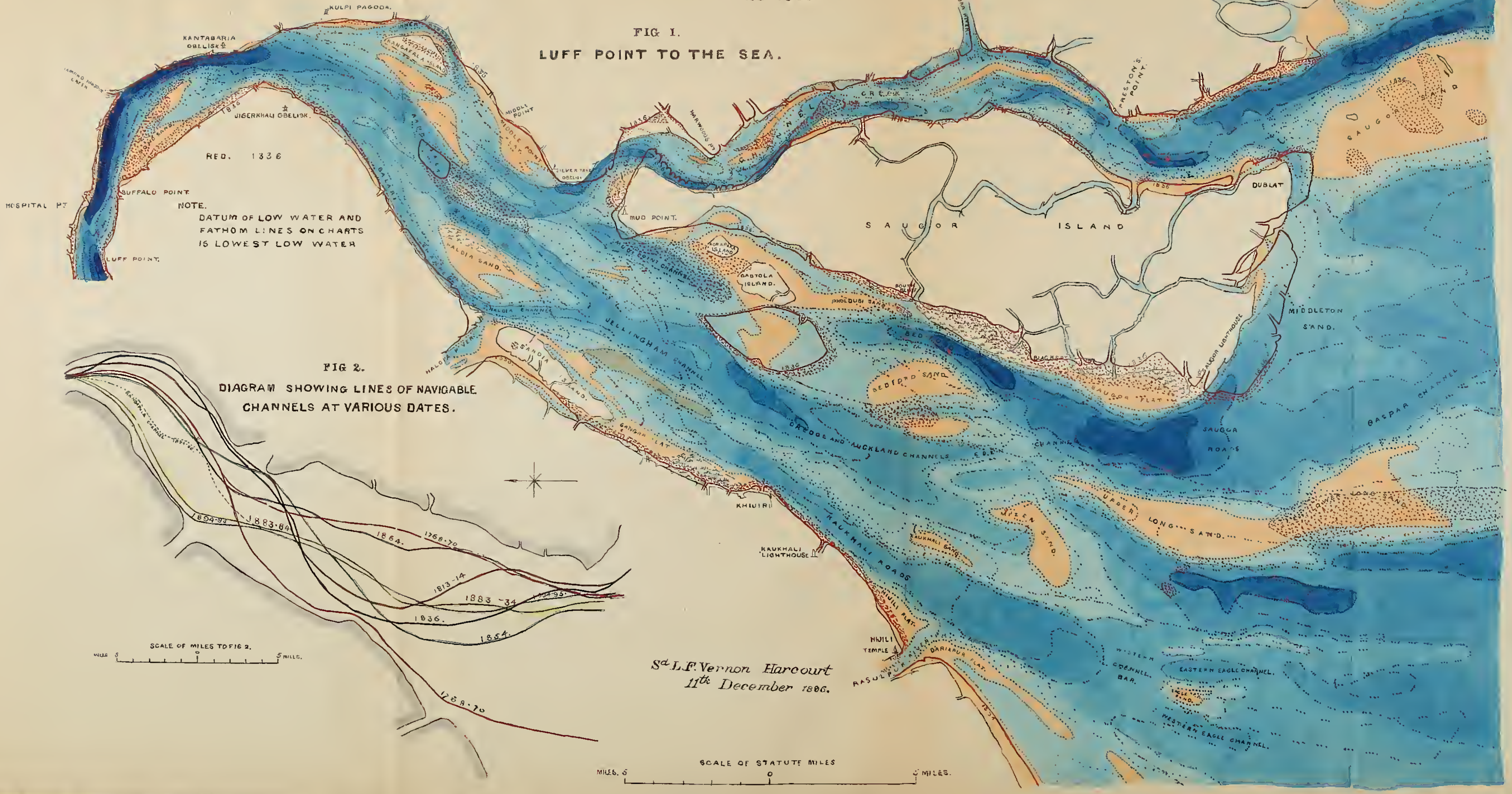
(34) L. F. Vernon Harcourt.
11th December, 1896.

RIVER HÚGLI.

PLAN No. 9.

ESTUARY 1888.

RED 1836.

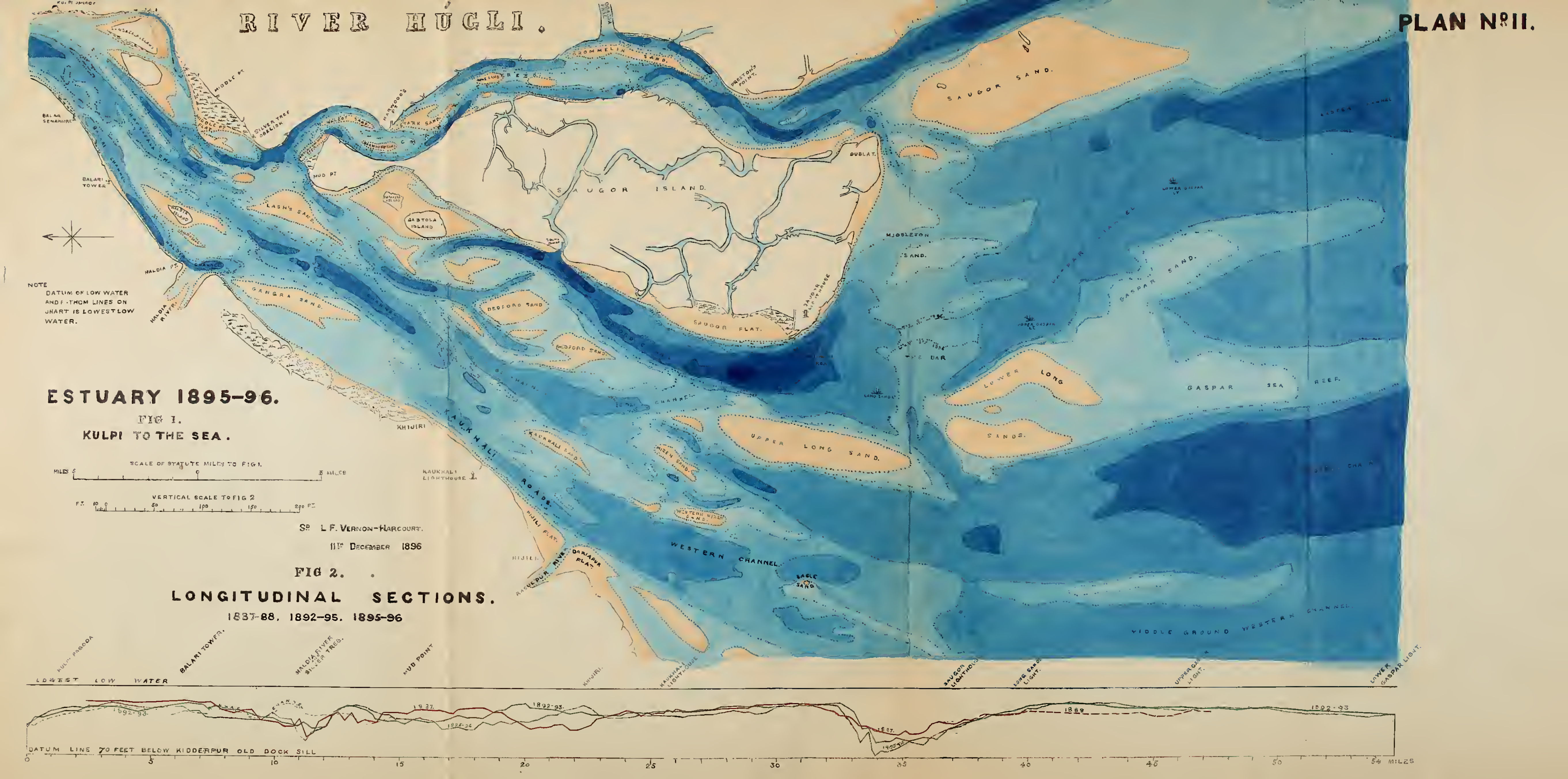


RIVER HÚGLI,

ESTUARY 1894-95.

RED 1883-84.

PLAN No. 10.



RIVER HUGLI.
PLAN No. II.
ESTUARY 1895–96.
FIG 1.
KULPI TO THE SEA.
SCALE OF STATUTE MILES TO FIG 1.
VERTICAL SCALE TO FIG 2
NOTE
DATUM OF LOW WATER AND FATHOM LINES ON CHART IS LOWEST LOW WATER.
Sr. L. F. Vernon-Harcourt.
11th December 1896
FIG 2.
LONGITUDINAL SECTIONS.
1837-88. 1892-95. 1895-96
SAUGOR ISLAND
SAUGOR SAND
SAUGOR FLAT
GASPAR SAND
GASPAR SEA REEF
LOWER LONG SANDS
UPPER LONG SAND
THE BAR
MIDDLETON SAND
DUBLAT
GABTOLA ISLAND
LASH'S SAND
GANGRA SAND
BEDFORD SAND
KAUKHALI ROADS
KAUKHALI LIGHTHOUSE
KHIJIRI
HIJILI FLAT
RASULPUR RIVER
DARIAPUR FLAT
WESTERN CHANNEL
EAGLE SAND
MIDDLE GROUND WESTERN CHANNEL
HALDIA PT.
HALDIA RIVER
BALARI TOWER
SILVER TREE OBELISK
MUD PT.
GROMMELIN SAND
PRESTON'S POINT
HARWOOD'S PT.
LOWEST LOW WATER
KULPI PAGODA
BALARI TOWER.
HALDIA RIVER SILVER TREE.
MUD POINT
KHIJIRI
KAUKHALI LIGHTHOUSE
SAUGOR LIGHTHOUSE
LONG SAND LIGHT.
UPPER GASPAR LIGHT.
LOWER GASPAR LIGHT.
1837
1889
1892-93
1895-96
DATUM LINE 70 FEET BELOW KIDDERPUR OLD DOCK SILL
0 5 10 15 20 25 30 35 40 45 50 54 MILES


PLAN No. 12.
RIVER HÚGLI.
SEA-FACE OF THE GANGES DELTA.
FIG. 1.
RED. 1837-40.
BLACK 1877-87
FIG. 2.
SANDHEADS.
RED 1768-70
BLACK 1837-40.
SCALE OF STATUTE MILES
FIG. 3.
RED. 1837-40.
BLACK 1896
WESTERN CHANNEL
EASTERN CHANNEL
SUNDERBUNS
SAUGOR ISLAND
RIVER HUGLI
TETULIA RIVER
MEGHNA RIVER
SANDWIP CHANNEL
CHITTAGONG RIVER
ARGO FLAT
BANGADUNI SAND
SWATCH OF NO-GROUND
BALASOR ROAD
EASTERN CHANNEL
GASPAR CHANNEL
20 FATHOM LINE
30 FATHOM LINE
50 FATHOM LINE
100 FATHOM LINE
SCALE OF STATUTE MILES.
MILES 10 5 0 10 20 30 40 50 MILES.
(Sd.) L. F. Vernon Harcourt
11th December. 1896.